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Draft PCB Chemical Action Plan

by

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- Name, Organization
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Summary of Findings

Most of this section will be written after the advisory committee process, when we are more confident in the information and have recommendations.

PBT Rule and Chemical Action Plans

A Chemical Action Plan (CAP) is a plan that identifies, characterizes, and evaluates uses and releases of a specific persistent, bioaccumulative, toxic chemical (PBT) or a group of Persistent, Bioaccumulative and Toxic chemicals and recommends actions to protect human health and the environment (173-333 WAC). PBTs are considered the "worst of the worst" chemical contaminants because they remain in the environment for a long time, and build up within organisms and/or the food chain.

This Polychlorinated Biphenyls (PCBs) CAP estimates releases of PCBs from various sources to air, land and water. It also describes the physical and chemical properties of PCBs and why they are considered toxic to humans and other organisms. The recommendations are a set of actions to reduce and phase out uses, releases, and exposures in Washington in consideration of current management approaches. An economic analysis on the cost of recommendations and the most promising options is also included.

PCBs occur as complex mixtures that include many PCB compounds. The overall toxicity of PCBs is caused by these mixtures and as a result Ecology chose to evaluate available information on all PCB compounds.

Toxic effects

xxx

Major sources

xxx

Pathways

xxx

Recommendations

xxx

Implementation Steps

xxx

General Chemical Information

Summary

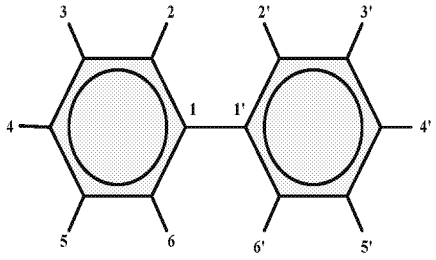

Figure 1: PCB Structure

Polychlorinated biphenyls (PCB) are a family of man-made chemicals consisting of two benzene rings joined together and containing one to 10 chlorine atoms attached to the benzene rings. There are 209 possible combinations of chlorine positions, called congeners. Depending upon the amount of chlorine present, PCBs appear as oily liquids to white crystalline solids and hard non-crystalline resins (HSDB, 2013). PCBs are hydrophobic and bind to particles. Due to their non-flammability, chemical stability, high boiling point and electrical insulating properties, PCBs were used in hundreds of industrial and commercial applications including electrical, heat transfer and hydraulic equipment; as plasticizers in paints, plastics, and rubber products; in pigments, dyes, and carbonless copy paper; and many other industrial applications (EPA 2013a).

From 1929 to 1977, 700,000 tons (or 1.4 billion lbs or 600,000 metric tons) of PCBs were commercially manufactured in the US (EPA 1997). Most of the PCBs in the US were manufactured by Monsanto, which continued manufacture in the US until 1977 when US production stopped. The 1976 Toxic Substances Control Act (TSCA) prohibited manufacture, processing, and distribution of PCBs with an effective date in 1977. Some legacy uses of PCBs were allowed to continue.

PCBs are identified as persistent, bioaccumulative and toxic (PBT). Because of their persistence, PCBs continue to be found in the environment and contamination from legacy sources remain a problem. In addition, PCBs are not prohibited in some products at concentrations below 50 ppm. PCB concentrations of less than 50 ppm are considered to be "PCB-free." Recent evidence has also indicated that PCBs may be found as contaminants in a wide range of consumer products because of the presence in several pigments and dyes (Hu, 2010, Rodenburg, 2010)

Physical and Chemical Properties of PCBs

A summary of typical characteristics for PCBs can be found in Table 1 (ATSDR 2000).

In general, PCB compounds range from heavy oily liquids to sticky resins, or melting crystalline solids depending upon the amount of chlorine present. These man-made compounds are odorless, colorless to light yellow or amber, and very stable and have relatively low volatility at ambient temperatures. PCBs were attractive in many applications because they resist breakdown at high temperatures or from aging, or oxidation. They persist in the environment since they do not easily biodegrade. PCBs are hydrophobic and thus do not dissolve well in water. As hydrophobic and very stable compounds, PCBs may volatilize from water despite their low vapor pressure. PCBs also easily adsorb onto organic particles in soils, sediments, biological systems, or water. (Panero et al. 2005) These organic particles can be transported long distances and has been shown as one of the reasons PCBs are distributed throughout the planet including remote areas.

Washington State's PBT Rule (WAC 173-333) defines persistence, bioaccumulation, and toxicity:

- The criterion for persistence is the half-life (the time it takes for half of the chemical to breakdown) of the chemical in water, soil, or sediment is greater than or equal to 60 days.
- The criterion for bioaccumulation is:
  - The bioconcentration factor (BCF) or bioaccumulation factor (BAF) in aquatic species for the chemical is greater than 1,000, or
  - In the absence of such data, the log-octanol water partition coefficient (log K_{ow}) is greater than five.
- In order for a chemical to be considered toxic, it must meet at least one of the following criteria:
  - Be a carcinogen, a developmental or reproductive toxicant, or a neurotoxicant.
  - Have a reference dose or equivalent toxicity measure that is less than 0.003 mg/kg/day.
  - Have a chronic no-observed-effect concentration (NOEC) or equivalent toxicity measure that is less than 0.1 mg/L or an acute NOEC or equivalent toxicity measure than is less than 1.0 mg/L.

Many but not all PCB congeners are persistent and bioaccumulative as defined in Washington's PBT Rule. Table 2 demonstrates persistence and bioaccumulation for a series of PCBs, one from each of the ten homolog groups as predicted by EPA's PBT Profiler (EPA 2012b). PCBs are often grouped by the total number of chlorine atoms and a group with the same number of chlorines is called ad homolog. Washington's PBT characteristics are included in the bottom of the table (WAC 173-333). Table 3 (IPCS 1995) provides ranges of characteristics for congener groups and also includes Washington's PBT characteristics on the bottom of the table.

Although the information in Table 2 is modeled data, which should not be confused with analytical results, the PBT Profiler results do demonstrate some trends. In general, persistence as indicated by the half-lives increases as the number of chlorine atoms increase. The tendency to bioaccumulate increases until the molecular structure of **the** PCB becomes large enough that the amount of bioaccumulation plateaus and begins to decrease. This plateauing is a direct result of the size of the PCB molecule, which can restrict transport through cell walls. Although all PCBs shown meet Ecology's persistence criterion, some of the mono-substituted may have sufficiently low bioaccumulation factors (BCF) that they may not meet Ecology's PBT criteria.

Table 1: Summary of Typical PCB (Aroclor) Physical Characteristics (from ATSDR 2000)

Property	Aroclor 1254	Aroclor 1260	Aroclor 1262	Aroclor 1268
Molecular weight	328	357.7	389	453
Color	Light yellow	Light yellow	No data	Clear
Physical state	Viscous liquid	Sticky resin	No data	Viscous liquid
Melting point, oC	No data	No data	No data	No data
Boiling point, oC	365-390	385-420	390-425	435-450
Density, g/cm3 at 25 oC	1.54	1.62	1.64	1.81
Odor	Mild hydrocarbon	No data	No data	No data
Solubility:				
Water, mg/L	0.012, 0.57 (24 oC)	0.0027, 0.08 (24 oC)	0.052 (24 oC)	0.300 (24 oC)
Organic solvent(s)	Very soluble	Very soluble	No data	Soluble
Partition coefficients:				
Log Kow	6.5	6.8	No data	No data
Vapor pressure, mm Hg at 25 oC	7.71x10-5	4.05x10-5	No data	No data
Henry's law constant, atm-m3/mol at 25 oC	2.0x10-3	4.6x10-3	No data	No data
Flashpoint, oC (Cleveland open cup)	No data	No data	195 oC	195 oC
Flammability limits, oC	None to boiling pt	None to boiling pt	None to boiling pt	None to boiling pt
Conversion factors				
Air (25 oC)	1 mg/m3= 0.075 ppm	1 mg/m3= 0.065 ppm	1 mg/m3= 0.061 ppm	1 mg/m3= 0.052 ppm

Table 1 continued

Property	Aroclor 1254	Aroclor 1260	Aroclor 1262	Aroclor 1268
Molecular weight	328	357.7	389	453
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Flammability limits, oC	None to boiling pt	None to boiling pt	None to boiling pt	None to boiling pt
Conversion factors				
Air (25 oC)	1 mg/m3= 0.075 ppm	1 mg/m3= 0.065 ppm	1 mg/m3= 0.061 ppm	1 mg/m3= 0.052 ppm

Table 2: EPA PBT Profiler Estimates of Persistence and Bioaccumulation for Select PCB congeners

PCB	Congener number	CAS	Half-Life (days)				BCF
			Water	Soil	Sed.	Air	
4-Chlorobiphenyl	PCB-3	2051-62-9	38	75	340	4.2	510
3,3'-Dichlorobiphenyl	PCB-11	2050-67-1	38	75	340	3.9	5,400
2,3,4'-Trichlorobiphenyl	PCB-22	38444-85-8	60	120	540	15	6,700
2,3',5,5'-Tetrachlorobiphenyl	PCB-72	41464-42-0	180	360	1,600	13	27,000
2,2',4,4'5-Pentachlorobiphenyl	PCB-99	38380-01-7	180	360	1,600	13	40,000
2,3,3',4,4',5-Hexachlorobiphenyl	PCB-156	38380-08-4	180	360	1,600	75	26,000
2,3,3',4,4',5,6'-Heptachlorobiphenyl	PCB-190	41411-64-7	180	360	1,600	130	12,000
2,2',3,3',4',5,5',6'-Octachlorobiphenyl	PCB-199	52663-75-9	180	360	1,600	290	5,900
2,2',3,3',4,4',5,6,6'-Nonachlorobiphenl	PCB-207	52663-79-3	180	360	1600	370	2,900
Decachlorobiphenyl	PCB-209	2051-24-3	180	360	1,600	880	12,000
WA PBT Characteristics			> 60	> 60	> 60		> 1,000

BCF = Bioconcentration Factor; half-life = the amount of time it takes for the concentration of a chemical to diminish to half its original value; N/A = Not Applicable

Table 3: PCB Homolog Chemical properties (IPCS, 1995)

Congener Group	CASRN	Molecular weight (g/molecular)	Vapour Pressure (Pa)	Water Solubility (g/m^3)	log K_{OW}
Monochlorobiphenyl	27323-18-8	188.7	0.9-2.5	1.21-5.5	4.3-4.6
Dichlorobiphenyl	25512-42-9	223.1	0.008-0.60	0.06-2.0	4.9-5.3
Trichlorobiphenyl	25323-68-6	257.5	0.003-0.22	0.015-0.4	5.5-5.9
Tetrachlorobiphenyl	26914-33-0	292.0	0.002	0.0043-0.010	5.6-6.5
Pentachlorobiphenyl	25429-29-2	326.4	0.0023-0.051	0.004-0.02	6.2-6.5
Hexacholorbiphenyl	26601-64-9	360.9	0.0007-0.012	0.0004-0.0007	6.7-7.3
Heptachlorobiphenyl	28655-71-2	395.3	0.00025	0.000045-0.000	6.7-7
Octachlorobiphenyl	55722-26-4	429.8	0.0006	0.0002-0.0003	7.1
Nonachlorobiphenyl	53742-07-7	464.2	-	0.00018-0.0012	7.2-8.16
Decachlorobiphenyl	2051-24-3	498.7	0.00003	0.000001-0.000	8.26
WA PBT Criterion					>5

log Kow = natural log of the octanol/water coefficient

Stability of Ring Structure and Carbon to Halogen Bond

The chemistry and related stability of ring compounds was discussed extensively in the Polycyclic Aromatic Hydrocarbon (PAH) Chemical Action Plan (CAP) (Ecology, 2012). Benzene (cyclohexa-1,3,5-triene) [1] is cyclohexane with three double bonds equally spaced throughout the molecule. Unlike compounds where the electrons forming the double bonds are localized around specific carbon atoms, the electrons in benzene's double bonds are equally shared among all six-carbon atoms. This is a defining characteristic of aromatic compounds. Benzene is typically represented by chemists as a six-carbon ring with a circle inside to represent the sharing of all electrons equally among the carbon atoms (Figure 2):

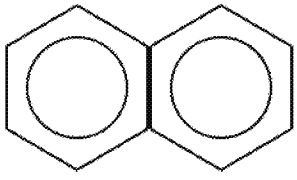


Figure 2: Chemical abbreviation for benzene

The most common theory currently accepted by chemists is that this sharing of electrons accounts for the thermodynamic stability of benzene and other aromatic compounds. Other theories have been promulgated (Cooper et al, 1986) but are not currently widely accepted. Regardless, the increased stability of benzene and benzene-based compounds like PCBs can be attributed to the unique ringed structure and sharing of electrons throughout the molecule.

PCBs have another feature which contributes greatly to their stability. Carbon and chlorine form a very strong bond and the amount of energy needed to break apart the bond is higher than most other covalent bonds. The strength of this bond greatly increases the ability of PCBs to persist in the environment. Persistence is also related to the number of chlorine atoms with increasing degree of persistence with increasing chlorine mass. Comparatively, the mono- and di-chlorobiphenyls are less persistent than the larger congeners; however, all PCBs meet the definition of persistence (see Table 2 for examples).

Naming of PCB congeners

PCBs have a variable structure with two benzene rings joined together. Each benzene ring can have one to five chlorine atoms attached. The number and location of the chlorine atoms attached

[1] The formal name for benzene describes a cyclical compound (cyclo) with six carbons (hexa) and three (tri) double bonds (ene). The '1,3,5' indicates which carbon atoms contain the double bond. Given the structure, the double bonds are represented as between the carbons 1 & 2, 3 & 4 and 5 & 6, although in reality the electrons are equally shared with all of the carbons on the ring.

to the biphenyl ring determine the physical properties and characteristics of the PCB congener. The position of the chlorine atoms are differentiated by using 2 through 6 for one benzene atom and 2' (two prime) through 6' (six prime) for chlorine atoms on the second benzene ring. The naming convention assumes that the two benzene molecules are joined together at the 1 and 1' position. See Figure 3 for the carbon numbering.

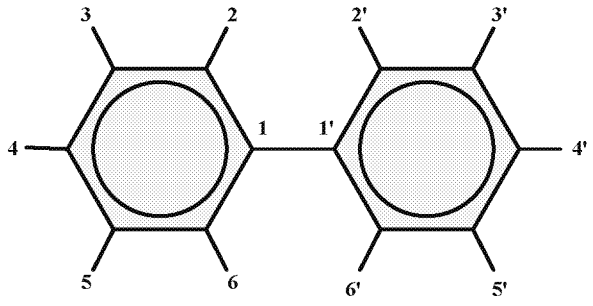


Figure 3: PCB Structure

This naming convention allows chemists to identify the structure of specific PCB congeners. For example, PCB-11 (3,3'-dichloro-1,1'-biphenyl or 3,3'-dichlorobiphenyl) contains two chlorine atoms in the 3 and 3' position. Unless indicated otherwise, a hydrogen atom is located on the benzene ring in all the unmarked locations.

Because it is possible for the PCB-11 molecule to rotate around the 1-1' carbon bond, there is no chemical difference between the above structure and 3,5'-dichlorobiphenyl (Figure 4).

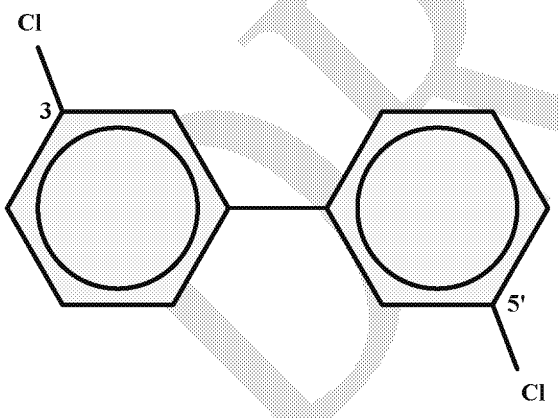


Figure 4: Alternate PCB-11 Structure

Several additional names potentially exist for PCB-11 including 5,3'-dichlorobiphenyl and 5,5'-dichlorobiphenyl. To prevent confusion, the naming convention uses the lowest numbers for these equivalent structures leading to PCB-11 being identified as 3,3'-dichlorobiphenyl. The naming convention can lead to confusion if an incorrect name is used.

Planar and non-planar PCBs

The issue of rotation can also have an impact on the relative toxicity of the PCB congeners. PCB congeners can either exist as planar where the two benzene rings are in the same plane or non-planar where the benzene rings are at 90 degree angle from each other. (ATSDR 2000) Planar and non-planar PCBs can have very different toxicity and this issue will be an important consideration in the relative toxicity of the PCB congeners discussed in subsequent sections.

A further naming convention using the terms ortho, meta and para are also used to identify the position of the chlorine atoms in a PCB molecule. If a chlorine atom is attached to the carbons adjacent to the 1 to 1' bond between the two benzene molecules, the chlorine atoms are said to be in the meta position. Table 4 and Figure 5 indicate the position of the chlorine atoms in a PCB congener using the three naming conventions:

Table 4: Table of location of chlorine atoms

Name	Carbon atom location
Meta	2,2,6,6'
Ortho	3,3',5,5'
Para	4,4'

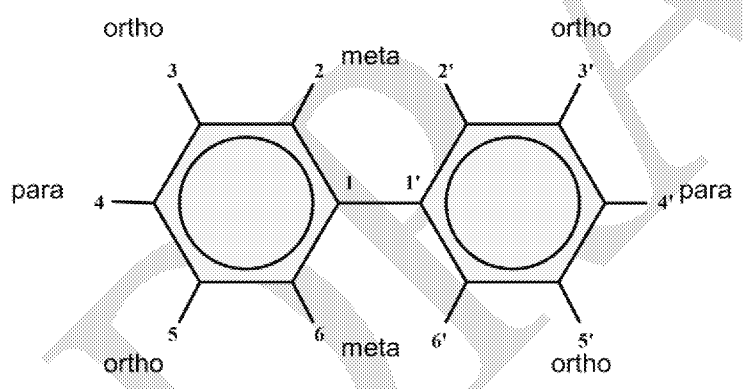


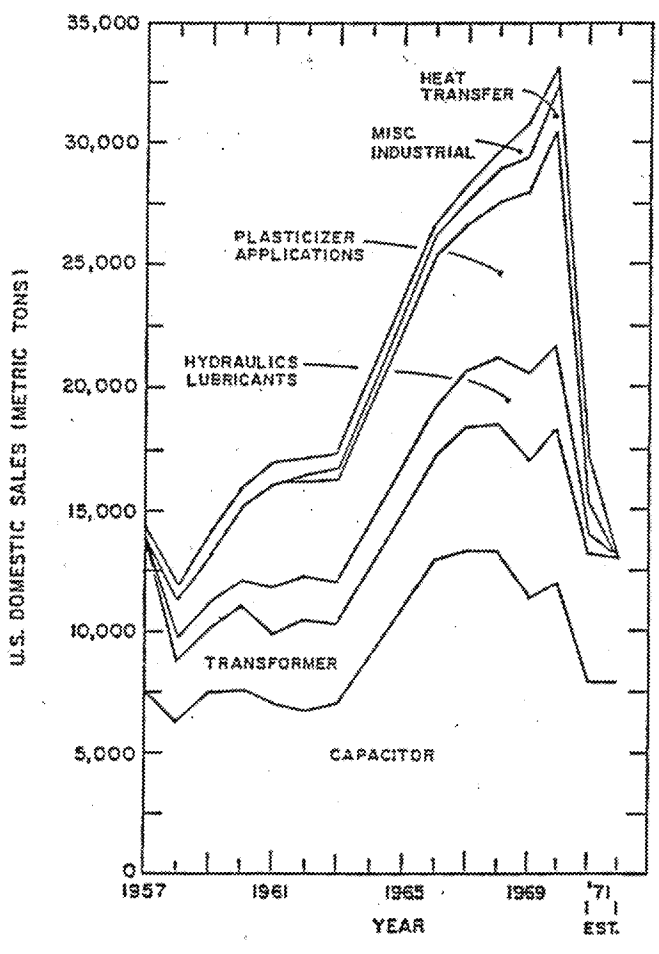
Figure 5: Location of meta, ortho, and para positions

The location of chlorine atoms plays an important role in the decomposition and toxicity of specific PCB congeners. Degradation reactions, for example, may selectively remove chlorine atoms from specific locations while PCB molecules with specific arrangements of chlorine atoms may have greater toxicity than related congeners.

Using the base structure (Figure 3), 209 different and unique PCBs (also known as congeners) can exist depending upon the number and position of chlorines involved. A list of these 209 congeners (EPA, 2003) can be found in Appendix A. In addition to specific congeners, PCBs are also often grouped by the total number of chlorine atoms also called homologs (Table 3).

Historic Manufacturing

Historically, PCBs were not manufactured as specific congeners or homologs but as mixtures. Globally there were a wide range of product names for PCB mixtures (Appendix B). There were nine major mixtures in the US called Aroclors (Table 5). Prior to 1971, the Monsanto Chemical Company produced Aroclors 1016, 1221, 1232, 1242, 1248, 1254, 1260, 1262, and 1268. (ATSDR 2000) Figure 6 shows the amounts and uses of PCBs produced in the US between 1957 and 1971. (EPA 1987). Most Aroclor mixtures are named utilizing a code. Most begin with a 12 and the last two digits indicate the percentage amount of chlorine in the mixture. Therefore Aroclor 1254 contained 54% chlorine by weight, Aroclor 1216 contained 16% chlorine, etc. The only major Aroclor mixture that deviates from this system is 1016.



In 1971, Monsanto voluntarily restricted the uses of PCBs and subsequently produced only Aroclor 1016, 1242, 1254, and small quantities of Aroclor 1221. In 1974, the Monsanto Chemical Company produced slightly more than 40 million pounds (18 million kg) of Aroclor mixtures. Of the total volume of Aroclors sold in the United States for that year, the percentages of the market for each of the Aroclors were: Aroclor 1016, 64%; Aroclor 1242, 17.9%; Aroclor 1254, 17.9%; and Aroclor 1221, 0.1%. The estimated, cumulative production and consumption volumes (in millions of pounds) of PCBs in the United States from 1930 to 1975 were: total production, 1,400 (635 million kg); imports, 3 (1.4 million kg); domestic sales, 1,253 (568 million kg); and exports, 150 (68 million kg) (ATSDR, 2000).

Figure 6: Monsanto Domestic sales of PCBs in the US by use (EPA 1987)

Table 5: Table of Aroclors (EPA 2013a)

CASRN	IUPAC Name
12674-11-2	Aroclor 1016
147601-87-4	Aroclor 1210
151820-27-8	Aroclor 1216
11104-28-2	Aroclor 1221
37234-40-5	Aroclor 1231
11141-16-5	Aroclor 1232
71328-89-7	Aroclor 1240
53469-21-9	Aroclor 1242
12672-29-6	Aroclor 1248
165245-51-2	Aroclor 1250
89577-78-6	Aroclor 1252
11097-69-1	Aroclor 1254
11096-82-5	Aroclor 1260
37324-23-5	Aroclor 1262
11100-14-4	Aroclor 1268
12767-79-2	Aroclor (unspecified)

These Aroclor mixtures can be fingerprinted depending upon the distribution of specific PCB congeners as indicated below (Figure 7) for the Aroclor 1254a mixture.

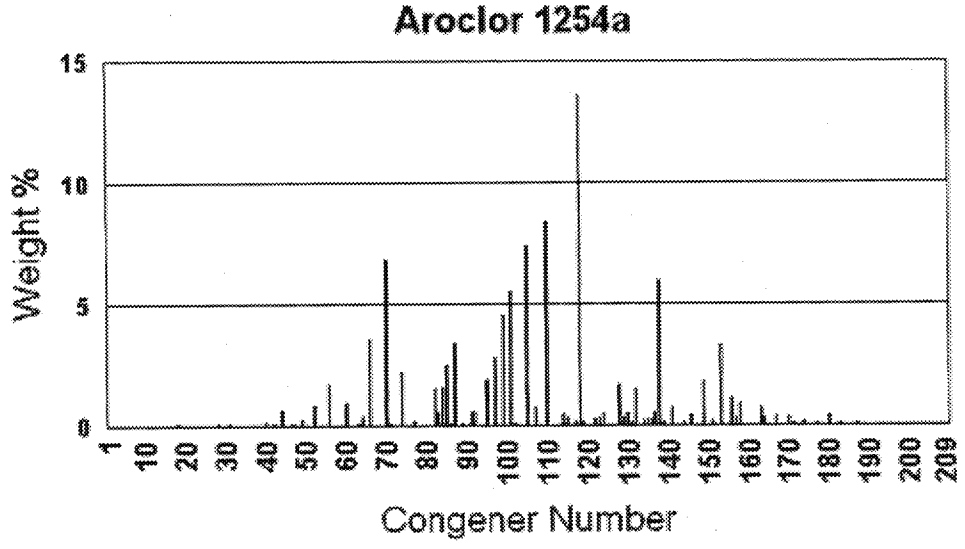


Figure 7: PCB Distribution in Aroclor1254a (EPA 2013e)

Additional fingerprints of common Aroclor mixtures can be found in Appendix C. Aroclor fingerprinting is important as it can point toward potential PCB sources when contamination has been found in the environment. However, due to differential uptake by organisms, differential

volatilization, and differential degradation, the congeners present in weathered mixtures in the environment will be different than the original congeners present in the Aroclors.

Analytical Methods

Because of their impact upon human health and the environment, considerable data exists on the presence of PCBs in a wide range of media. Historically, analytical methods were developed based upon the Aroclor fingerprints or values for total PCB concentrations. Recently, more sensitive and detailed congener-specific analyses have been developed to enable more detailed study of PCBs in the environment. PCBs are regulated under the Toxics Substances Control Act (TSCA), other Federal regulations (EPA 2013f) and state regulations such as Washington State's Dangerous Waste Regulations (WAC 173-303). Special analytical methods have been developed to meet these regulatory requirements. Methods range from traditional gas chromatography (GC), more recent high resolution GC mass spectroscopy, to new immunoassay techniques.

Numerous methods (Table 6) have been developed to analyze PCBs in a wide range of media using techniques with variable costs and detection levels. Although the list is not complete, it is indicative of the variety and type of methods currently available to test samples for PCBs.

For the purposes of this CAP, the three most commonly used analytical methods will be discussed in more detail:

- Aroclor methods
- Congener specific methods
- Screening methods

Table 6: Methods developed to test for PCBs in a wide range of media (NEMI, 2013)

Method Number	Source	Method Descriptive Name	Detection Level	Instrumentation	Relative Cost
530021	Abraxis	PCBs by Immunoassay, Lower Chlorinated, Magnetic Particle	5 ppb	IA	$
530011	Abraxis	Coplanar PCBs by Immunoassay, Microtiter Plate	14 ng/L	IA	$
530001	Abraxis	PCBs by Immunoassay, Higher Chlorinated, Magnetic Particle	.1 ppb	IA	$
505	EPA-NERL	Pesticides and PCBs in Water GC-ECD	N/A	GC-ECD	$$$
525.3	EPA-NERL	Organics in Water Using GCMS	N/A	GC-MS	$$$
508A	EPA-NERL	PCBs by GC-ECD	N/A	GC-ECD	$$$
508.1	EPA-OGWDW/TSC	Chlorinated Pesticides, Herbicides, and Organohalides in Water by GC-ECD	N/A	GC-ECD	$$$
8082A	EPA-RCRA	Polychlorinated Biphenyls (PCBs) by GC	N/A	GC-ECD/ELCD	$$
508	EPA-TSC/NERL	Chlorinated Pesticides in Water Using GC-ECD	N/A	GC-ECD	$$$
ET013	Envirologix	PCB (polychlorinated biphenyl) immunoassay	.3 µg/g	IA	$
A00134	MWI	PCB (polychlorinated biphenyl) in water by immunoassay	.2 µg/L	IA	$
A00134/A00137	MWI	PCB (polychlorinated biphenyl) in soils/sediment by immunoassay	.5 µg/g	IA	$
130.10	NOAA NST	Organic contaminants in marine sediments by GC-ECD	.05 ng/g	GC-ECD	$$$
130.11	NOAA NST	Organic contaminants in marine animal tissues by GC-ECD	.05 ng/g	GC-ECD	$$$
SPMDs	USGS	Passive sampling of organic compounds in water, air, and soils/sediments by SPMDs	N/A	SPMD	$$$$
O-1104	USGS-NWQL	Organochlorine and organophosphorous compounds, dissolved	.01 µg/L	GC-ECD	$$$
O-3104	USGS-NWQL	Organochlorine and organophosphorous compounds, total recoverable	.01 µg/L	GC-ECD	$$$
O-5129-95	USGS-NWQL	Organochlorine Pesticides and Gross PCBs in Bottom Sediment by GC	50 µg/kg	GC-ECD	$$$$
525.2	EPA-NERL	Organics in Water Using GCMS	.11 µg/L	GC-MS	$$$
1668a (Tissue)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Tissue by HRGC/HRMS	.011 ng/g	GC-MS	$$$$
1668a (Water)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Aqueous Samples by HRGC/HRMS	112 pg/L	GC-MS	$$$$
1668a (Soil/Sediment)	EPA-OGWDW/TSC	Chlorinated Biphenyls in Soil, Sediment, and Mixed Samples by HRGC/HRMS	.011 ng/g	GC-MS	$$$$

ECD = Electron capture detector

ELCD = Electrolytic conductivity detector
GC = Gas Chromatography
HRGC = High Resolution Gas Chromatography
HRMC = High Resolution Mass Spectroscopy
MS = Mass Spectroscopy
MWI = Modern Water Inc.

NERL = New England Regional Laboratory
NOAA = National Oceanographic and Atmospheric Association

NST = National Standards and Trends
NWQL = National Water Quality Laboratory
OGWDW = Office of Ground Water and Drinking Water
RCRA = Resource Conservation and Recovery Act
SPMD = Semipermeable membrane device

TSC = Technical Support Center
USGS = United States Geological Survey

Aroclor detection

EPA developed specific methods to comply with TSCA and other applicable legislation. In order to meet the requirements of the Resource Conservation and Recovery Act or RCRA (EPA, 1976), EPA developed Test Methods for Evaluating Solid Waste, Physical/Chemical Methods, more commonly known as SW-846 (EPA 2012a). Included in SW-846 are two specific methods for analyzing PCBs in a wide range of media:

- Method 8082A: Polychlorinated Biphenyls (PCBs) by Gas Chromatography
- Method 8275A: Semi-volatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS)

Method 8082A is the more traditionally used and is responsible for much of the legacy data reported as Aroclor mixtures or specific PCB congeners identified in the method. Method 8082A is '*... used to determine the concentrations of polychlorinated biphenyls (PCBs) as Aroclors or as individual PCB congeners in extracts from solid, tissue, and aqueous matrices, using open-tubular, capillary columns with electron capture detectors (ECD) or electrolytic conductivity detectors (ELCD).*' (EPA, 2012a) The specific chemicals reported by this method (Table 7) are detected in the parts per billion (ppb) to parts per million (ppm) levels depending upon complexity of sample and matrix involved.

Congener detection

As technology improved and the need for congener specific analysis was identified, Method 1668C (USGS, 2010) was developed. Method 1668C was created to analyze PCBs in water, soil, sediment, biosolids and tissue. It provides analytical results for '*... the 12 polychlorinated biphenyls (PCBs) designated as toxic by the World Health Organization (WHO): congeners 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, and 189* [and] *the remaining 197 CBs* [chlorinated biphenyls], *approximately 125 of which are resolved adequately on an SPB-octyl gas chromatographic column to be determined as individual congeners. The remaining approximately 70 congeners are determined as mixtures of isomers (co-elutions).*' (EPA, 2010) Method 1668C requires the use of a high-resolution mass spectrometer for detection and therefore is considerably more expensive than Method 8082. Method 1668C, however, is becoming more common as concerns have been raised about PCBs from non-legacy sources and potential degradation products from legacy Aroclor mixtures. Detection limits for Method 1669C can be in the ppm to ppb levels depending upon complexity of sample and matrix involved.

Table 7: PCBs reported by Method 8082A (EPA 2012a)

Compound	CAS Registry No.	IUPAC #
Aroclor 1016	12674-11-2	-
Aroclor 1221	11104-28-2	-
Aroclor 1232	11141-16-5	-
Aroclor 1242	53469-21-9	-
Aroclor 1248	12672-29-6	-
Aroclor 1254	11097-69-1	-
Aroclor 1260	11096-82-5	
2-Chlorobiphenyl	2051-60-7	1
2,3-Dichlorobiphenyl	16605-91-7	5
2,2',5-Trichlorobiphenyl	37680-65-2	18
2,4',5-Trichlorobiphenyl	16606-02-3	31
2,2',3,5'-Tetrachlorobiphenyl	41464-39-5	44
2,2',5,5'-Tetrachlorobiphenyl	35693-99-3	52
2,3',4,4'-Tetrachlorobiphenyl	32598-10-0	66
2,2',3,4,5'-Pentachlorobiphenyl	38380-02-8	87
2,2',4,5,5'-Pentachlorobiphenyl	37680-73-2	101
2,3,3',4',6-Pentachlorobiphenyl	38380-03-9	110
2,2',3,4,4',5'-Hexachlorobiphenyl	35065-28-2	138
2,2',3,4,5,5'-Hexachlorobiphenyl	52712-04-6	141
2,2',3,5,5',6-Hexachlorobiphenyl	52663-63-5	151
2,2',4,4',5,5'-Hexachlorobiphenyl	35065-27-1	153
2,2',3,3',4,4',5-Heptachlorobiphenyl	35065-30-6	170
2,2',3,4,4',5,5'-Heptachlorobiphenyl	35065-29-3	180
2,2',3,4,4',5',6-Heptachlorobiphenyl	52663-69-1	183
2,2',3,4',5,5',6-Heptachlorobiphenyl	52663-68-0	187
2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl	40186-72-9	206

Screening methods

In response for a need by industry to test wastes quickly and cheaply, manufacturers developed screening methods to test specific waste types. These methods were reviewed and adopted by EPA into SW-846. Specifically, PCB applicable screening methods listed in SW-846 include:

- Method 9077: Test Methods for Total Chlorine in New and Used Petroleum Products (Field Test Kit Methods)
- Method 9078: Screening Test Method for Polychlorinated Biphenyls in Soil
- Method 9079: Screening Test Method for Polychlorinated Biphenyls in Transformer Oil
- Method 4020: Screening for Polychlorinated Biphenyls by Immunoassay

Method 9077 is '… used to determine if a new or used petroleum product meets or exceeds requirements for total halogen measured as chloride. An analysis of the chlorine content of petroleum products is often required prior to their use as a fuel. The method is specifically

designed for used oils, permitting onsite testing at remote locations by nontechnical personnel to avoid the delays for laboratory testing' (EPA, 2012a). It provides results ranging from 300 to 4,000 parts per million (ppm).

Method 9077, however, tests for total chlorine and cannot differentiate PCBs from other chlorinated species such as chlorinated solvents commonly used in industry. Methods 9078 and 9079 test specifically for PCBs. Method 9078 is '*…used to determine the amount of PCB (polychlorinated biphenyl) contamination in soils such as sand, gravel, loam, sediment, and clay, assuming that PCBs are the sole source of organic halogens in the sample.*' Detection levels range from 2 to 2,000 ppm PCBs. The method provides inaccurate results if other chlorinated species are present and should be used with caution. However, in those instances where PCB contamination is known, it provides a quick and easy method to determine the extent of contamination and is often used as a screening tool to limit the number of samples sent to a laboratory for more detailed analyses.

Method 9079 is '… used to screen hydrocarbon based electrical insulating fluids for polychlorinated biphenyls (PCBs) at preset levels of 20, 50, 100, or 500 µg/g [ppm].' The method is calibrated using Aroclor 1242 as a standard and results for other Aroclor mixtures may vary slightly. Method 4020 is '… a procedure for screening soils and non-aqueous waste liquids to determine when total polychlorinated biphenyls (PCBs) are present at concentrations above 5, 10 or 50 mg/kg.' Method 4020 only works on soils containing more than 0.625 ppm PCBs.

Used correctly, Methods 9078, 9079 and 4020 are specifically designed to help meet regulatory requirements. Simple PCB kits meeting the requirements of these methods include but are not limited to:

- Dexsil® Clor-N-Oil Field Test Kit[2]
- Dexsil® Clor-N-Soil Field Test Kit[3]
- Dexsil® Clor-d-tect Field Test Kit[4]
- EnSys Field Test[5]
- RaPID Assasy Field Test[6]

In addition to these wet chemical methods, several simple instrumentation and detection kits are also available to test for PCBs including, but are not limited to:

- Dexsil® L2000DX PCB/Chloride Analyzer System (LP-2000)[7]

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[2] More information available at: http://www.dexsil.com/products/detail.php?product_id=2, accessed 7/2013.
[3] More information available at: http://www.dexsil.com/products/detail.php?product_id=4, accessed 7/2013.
[4] More information available at: http://www.dexsil.com/products/detail.php?product_id=29, accessed 7/2013.
[5] More information available at: http://www.tttenviro.com/store/ensys, accessed 7/2013.
[6] More information available at: http://www.tttenviro.com/store/rapid-assay, accessed 7/2013.
[7] More information available at: http://www.dexsil.com/products/detail.php?product_id=13, accessed 7/2013.

- Hach® PCB in Soil Pocket Colorimeter II Test Kit[8]
- Hach® DR 2700™ Portable Spectrophotometer[9]

These field test kits are useful as they allow detection for PCBs in the field by individuals with limited technical knowledge and expertise.

[8] More information available at: http://www.hach.com/pcb-in-soil-pocket-colorimeter-ii-test-kit/product-parameter-reagent?id=7640220978, accessed 7/2013.
[9] More information available at: http://www.hach.com/dr-2700-portable-spectrophotometer/product?id=7640439006&callback=bp, accessed 7/2013.

PCB Uses and Sources

Legacy

Historically, PCBs were used in closed systems such as electrical transformers and capacitors, heat transfer and hydraulic systems and vacuum pumps and lubricants, and open systems such as surface coatings, adhesives, plasticizers inks, insulating materials and pesticides (UNEP, 1999). PCBs were valued for their stability, inability to conduct electricity and anti-microbial effects. 60% of worldwide and 77% of US production was used in the production of transformers of capacitors and total worldwide production from 1929 to 1989 is estimated at 1.2 million tons (Tanabe 1988).

PCBs were intentionally added to some products in open applications where the PCBs are in direct contact with the environment and may be transferred from the product into the environment. Plasticizers were the most common use of PCBs in products such as PVC (polyvinyl chloride), neoprene and other chlorinated rubbers. PCBs have also been used in paints and surface coatings as flame retardants and adhesives as plasticizers (UNEP 1999). PCBs were often added to caulk and paint in the field at varying amounts.

Current levels in the environment are due to cycling of PCBs from these historical uses with additional releases of PCBs from legacy uses and new inadvertently produced by-products of chemical manufacture. Specific Aroclor mixtures were often used in specific applications (Table 8). Companies have found alternatives for most PCB uses.

Table 8: Historical Aroclor Uses (from ATSDR 2000)

End Use	Aroclor								
	1016	1221	1232	1242	1248	1254	1260	1262	1268
Capacitors	•	•				•			
Transformers				•		•	•		
Heat transfer				•					
Hydraulics/lubricants									
Hydraulic fluids			•	•	•	•	•		
Vacuum pumps					•	•			
Gas-transmission turbines		•		•					
Plasticizers									
Rubbers		•	•	•	•	•			•
Synthetic resins					•	•	•	•	•
Carbonless paper				•					
Miscellaneous									
Adhesives		•	•	•	•	•			
Wax extenders				•		•			•
Dedusting agents						•	•		
Inks						•			
Cutting oils						•			
Pesticide extenders						•			
Sealants/caulks						•			

Inadvertent Generation

PCBs may be found as contaminants in a wide range of chemical processes involving chlorine and can be found in recycled materials contaminated with PCBs. As part of 1984 TSCA rulemaking on PCBs the EPA identified about 200 chemical processes that may inadvertently create PCBs and narrowed the list to 70 chemical processes that are likely to contain PCBs as contaminants from manufacturing processes (Panero et al., 2005). Most of these chemical processes have not been evaluated to determine if PCBs are actually a reaction byproduct and present in the final product. In addition there are other processes that may inadvertently generate PCBs that are not on this list. Nor have these processes been analyzed to determine how inadvertently generated PCB enters the consumer supply chain

Recent studies have shown that PCBs can still be found in products. Many of these products contain PCBs as an impurity created during the production process. Inadvertent sources include contaminants or byproducts from manufacturing processes using chlorinated compounds either as a reaction component or solvent. As shown in Table 9 PCBs have been found in various pigments at substantial levels (EPA 1982).

Table 9: PCBs congeners found in specific pigments (EPA 1982)

PCB Congeners	Pigment	Levels found (ug/g or ppm)
PCB-11	Diarylide yellow	70
PCB-209	Phthalocyanine green	40
Mix of penta- and hexa-	Phthalocyane blue	90*

*Total of PCB congeners

According to one of the rules created by EPA to implement TSCA (49 FR 28172) products may contain low levels of PCBs if the certain conditions are met (see section on Regulations).

Over the last few years, researchers have begun to test consumer products for the potential presence of PCBs. Numerous organic pigments and dyes exist that may contain PCBs as an unintentional byproduct including diarylides (yellow and orange), naphtharylamides (oranges and reds), phthalocyanines (blue), and basic dye complex pigments (reds, violets, blues and greens) (Christie, 2013). In general pigments are insoluble in their application medium and dyes are soluble, with inks mostly being used for textile coloration and pigments having broader uses (Christie 2013, Guo 2013). Many of these pigments fall into the broad category of azo compounds. An azo compounds contain one or more double-bonded nitrogen atoms (R-N=N-R′) where R and R′ are organic additions with varying degrees of complexity. Azo compounds are very efficient at absorbing light and emitting the radiation in specific wavelengths, thereby providing specific colors. Chlorinated compounds are often used in azo pigments as they can greatly increase the lifetime of the resultant product.

Hu et al. conducted sampling of consumer paints containing specific azo (yellow) and phthalocyanine (blue and green) organic pigments and found PCB levels ranging from 2 to 200 ppb in 15 of 33 consumer paints tested. PCB-11 is also found in printed materials (Table 10) from various locations around the world (Guo, 2013).

Table 10: PCB-11 worldwide concentrations from printed materials (Guo, 2013)

Printed Material (Country)	PCB 11 concentration (ng/g or ppb)
Black and white printed newspaper (Georgia)	1.6
Black and white printed newspaper (Moldova)	9.7
Black and white printed newspaper (China)	15
Color newspaper (Georgia)	6.5
Color newspaper (Moldova)	16
Food packaging box (Czech Republic)	6.8
Food packaging box (Ukraine)	5.0

Diarylide yellow comprises approximately 25% of the 250 million tons of organic pigments produced yearly worldwide (Rodenberg, 2012) and testing has shown PCBs and especially PCB-11 are produced during pigment manufacture. PCB-11 is part of the structure of diarylide yellow (Figure 8) as indicated in the red box. PCB-11 can be produced either as a byproduct during the manufacturing process or from degradation of the pigment.

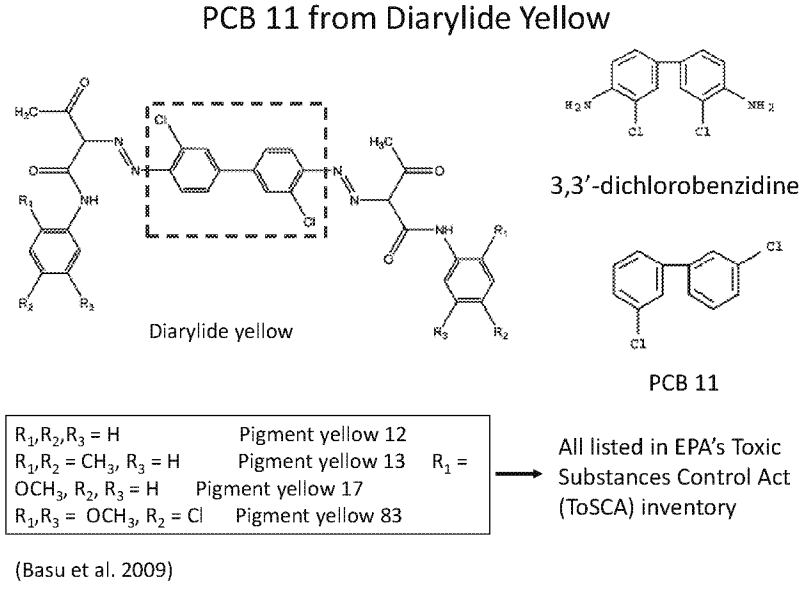

Figure 8: Diarylide yellow and PCB-11 (Rodenburg, 2012)

In addition to PCB-11, purification of the inorganic pigment titanium dioxide (TiO_2) produces larger molecular weight PCBs as a byproduct (Rodenburg, 2012). Chlorine is reacted at high

temperatures with titanium dioxide (TiO_2) ores containing other metal oxides such as rutile (TiO_2) or ilmenite ($FeTiO_3$) to form titanium tetrachloride ($TiCl_4$) which as a liquid is easily collected. $TiCl_4$ is then reacted with oxygen to make pure TiO_2 (UNEP, 2007). During this product process, the larger molecular weight PCBs are created as a reaction byproduct.

Titanium dioxide can also be produced by a sulphate process that does not generate PCB contamination. The sulfate process uses 2.4-3.5 tons of concentrated sulfuric acid (H_2SO_4) per ton of titanium dioxide and the process creates large amounts of acid waste that must be further treated. The chloride process does not generate spent acids and therefore creates less waste to be dealt with. (UNEP, 2007)

Research is continuing on alternatives to the organic azo pigments. The main challenges faced with replacements (Christie, 2013) are:

- Required color performance
- Required degree of transparency or opacity
- Level of fastness or permanence to light, solvents, heat, chemicals, etc. demanded by specific applications
- Cost effectiveness
- Acceptable toxicological and environmental profile.

Research is continuing and alternatives have been identified which appear to address many of these concerns (Christie, 2013).

Combustion

Lastly, PCBs are formed through incomplete combustion of products containing carbon and a chlorine source (ATSDR 2000). Given the widespread use of chlorinated compounds such as polyvinylchloride for packaging, tubing and other applications, incomplete combustion forms a wide range of halogenated compounds such as chlorinated dioxins and furans and PCBs. Most municipal incinerators are not effective in destroying PCBs and it is recommended that PCB-contaminated waste be burned at temperatures above 1,100 degrees Celsius and that care is taken with the temperature, residence time and turbulence of the waste in order to guarantee complete combustion (UNEP 1999).

Methods of Manufacturing

PCBs were first mentioned in a publication in Germany in the 1880s. The Swann Chemical Company in Anniston, Alabama was the first US company to manufacture PCBs commercially by bubbling benzene through molten lead to create biphenyl with subsequent chlorination of the biphenyl. Monsanto purchased the Swann Chemical Company in 1935 (Erickson and Kaley 2011).

Much has been written about the methods in which PCBs were manufactured (NYAS 2005; ATSDR 2000; Pomerantz 1978). Similar methods were used to manufacture PCBs with the main variable being the starting materials of biphenyl and naphthalene. The manufacturing process for Aroclors involved the '*... chlorination of biphenyl with anhydrous chlorine in the presence of a catalyst, such as iron filings or ferric chloride. The degree of chlorination, which determines the nature of the Aroclor, was controlled by the chlorine-contact time (range, 12–36 hours) in the reactor.*' (ATSDR 2000)

Once the manufacturing process was complete, '*The crude product [was] blown with air, and a small amount of lime ... added to remove hydrogen chloride and ferric chloride. The resulting chlorinated mixtures [were] batch-distilled to remove color and traces of hydrogen chloride and ferric chloride*' (HSDB 2013).

PCBs were also created using naphthalene which was '*... reacted to varying degrees with chlorine to produce a number of compounds designated by various trade names such as* ***Aroclor***' (HSDB 2013).

Environmental Transformation and Degradation

Although very stable in the environment, the major pathways for degradation (ATSDR, 2000) are:

- Vapor phase degradation with hydroxyl radicals
- Photolysis in water
- Aerobic biodegradation (preferentially less chlorinated congeners)
- Anaerobic microbial degradation (more highly chlorinated congeners favored)

PCBs in the atmosphere undergo complicated reactions (Figure 9) primarily with hydroxyl radicals created when water absorbs sunlight and separates into hydroxyl (•OH) and hydrogen (•H) radicals. Reactions with hydroxyl radicals are most prevalent. A radical is an atom or chemical that has a net charge of zero (neither negative nor positive) but has less than the preferred number of electrons in its outer shell. This instability causes a radical to be very reactive (ATSDR, 2000).

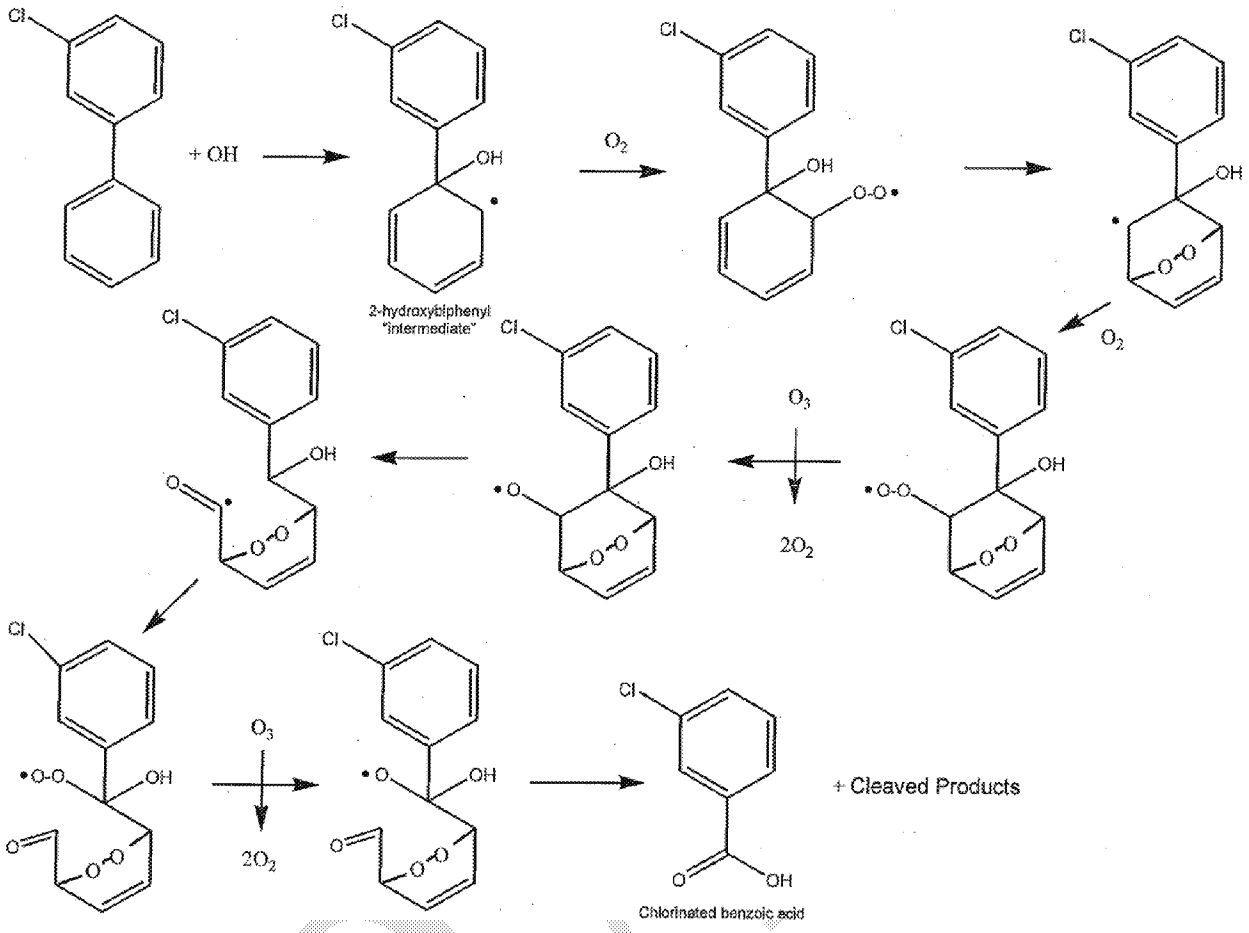

Figure 9: Hydroxyl photo-degradation pathways for PCBs in air (ATSDR, 2000)

In water, photolysis is the primary pathway for degradation as other more common reaction mechanisms such as hydrolysis and oxidation do not appear to contribute substantially. In these reactions, a carbon to chlorine bond absorbs energy from sunlight and separates into PCB and chlorine radicals. The PCB radical reacts with water forming a stable PCB compound but with one less chlorine (Figure 10). This reaction is particularly important for the larger PCBs as the more chlorines present, the easier it is to cleave a carbon to chlorine bond. In large PCB molecules, cleavage occurs preferentially on the ring with the most carbons. (ATSDR, 2000)

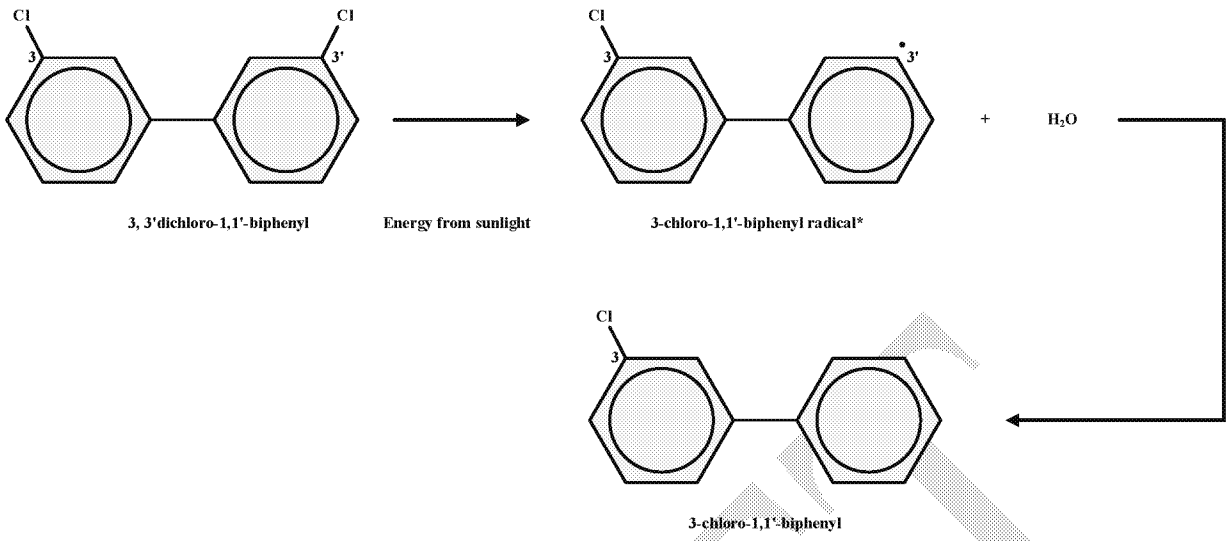

Figure 10: Photolysis of PCB-11

In sediment and soil, no abiotic process is known that significantly degrades PCBs. PCBs, however, have been found to degrade readily in both aerobic and anaerobic conditions. Both bacterial and fungal species have been shown to biodegrade PCBs using aerobic processes. Because of size restrictions, PCBs with 1 to 4 chlorine atoms are mostly likely to be degraded under aerobic conditions via a two step process (Figure 11). First, one of the two benzene rings is oxygenated and separated from the other ring. The remaining benzene ring is left as a chlorobenzoic acid. This combined process is called cometabolism.

After cometabolism has occurred, the remaining chlorobenzoic acid is further broken down into water and carbon dioxide (mineralization) in a series of reactions that continually add oxygen to the compound. Aerobic biodegration of PCBs also occurs primarily in soil and surface sediments. Interestingly, PCBs with fewer chlorine atoms (1-3) degrade faster than those with more chlorine atoms. This causes a fractionating effect where less chlorinated species biodegrade first while those with higher levels of chlorine atoms are left behind for long-term build up in the environment. (ATSDR, 2000)

Anaerobic degradation of PCBs is a much slower process compared with aerobic degradation and occurs primarily by reductive dechlorination where chlorine atoms are removed one after the other from a PCB molecule. At least eight distinct and complicated anaerobic pathways have been identified which may occur alone or in combination. Different pathways may favor chlorine in specific positions on the PCB molecule. (ATSDR, 2000)

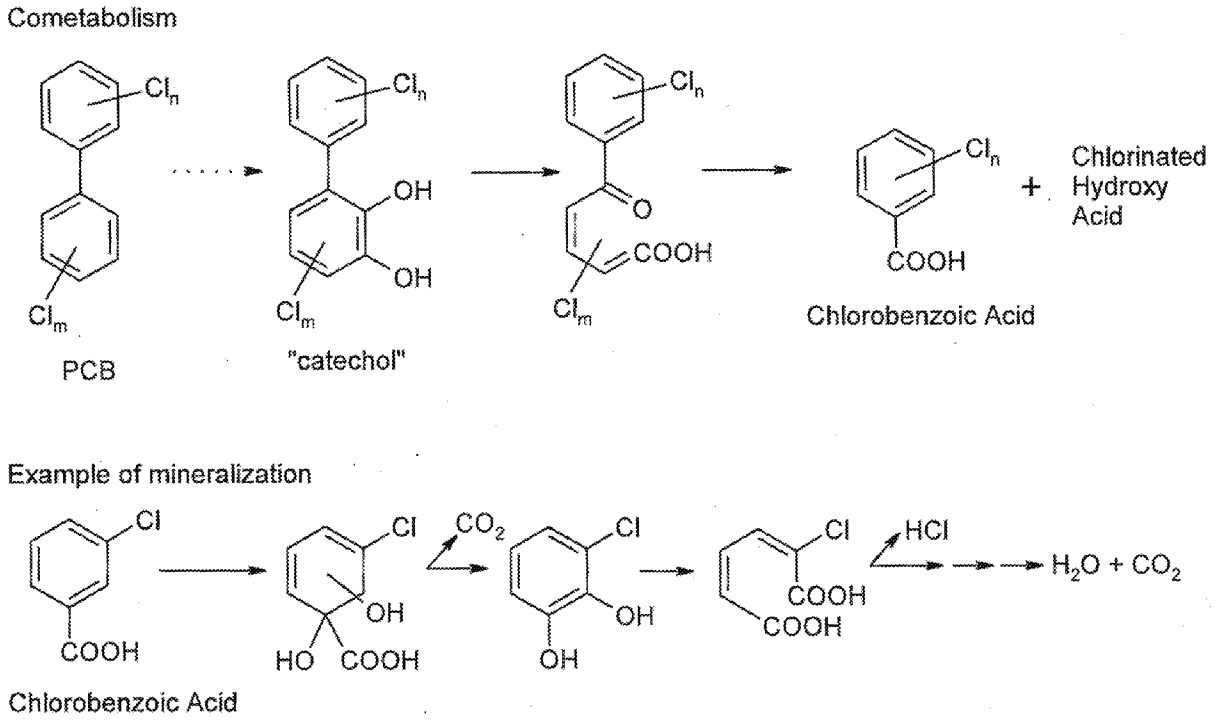

Figure 11: Pathways for Aerobic Degradation of PCBs (ATSDR, 2000)

Production, Uses, and Releases

According to the PBT Rule (WAC 173-333) chemical action plans (CAPs) include a section on "production, uses and releases" that contains information on the production of the chemical and estimates on the amount of the PBT used and released from all sources or activities in Washington.

From 1929 to 1977 the production of PCBs in the U.S. was approximately 1.4 billion lbs (600,000 metric tons), with the largest use for electrical equipment (EPA, 1997). Monsanto, the primary manufacturer of PCBs in North America, voluntarily limited production to certain Aroclors in 1971 (ATSDR 2000) and commercial production was stopped by 1977 under TSCA.

Table 11: Industrial Uses of PCBs (1929-1975) from EPA 1997

PCB Use	Pounds (millions)	Percentage of Total
Capacitors	630	50.3%
Transformers	335	26.7%
Placticizer uses	115	9.2%
Hydraulics and lubricants	80	6.4%
Carbonless copy paper	45	3.6%
Heat transfer fluids	20	1.6%
Petroleum additives	1	0.1%
Miscellaneous industrial uses	27	2.2%
TOTALS	1,253	100.0%

Transformers and capacitors are considered to be closed uses. There are partially closed uses, such as hydraulic fluids, heat exchange fluids, and gas pipelines. There is a much larger variety of open uses:

- Adhesives and tapes
- Antifouling compounds
- Carbonless copy paper
- Caulking/sealants
- Ceiling tiles
- Coal-tar enamel coatings
- Electrical cable insulation
- Fabric
- Flame retardant coatings
- Inks
- Insulation
- Lubricants
- Microscope immersion oil
- Paint
- Pesticide extenders
- Plastics
- Rubber gaskets/parts
- Sound-proofing materials

[PAGE * MERGEFORMAT]

- Floor waxes and sealers
- Grout
- HVAC components
- Varnish
- Waterproofing compounds
- Window glazing

We do not have enough information to estimate the historic use of PCBs in all of these applications or how much is still in use in Washington. Appendix E shows the known maximum concentration of products containing PCBs from the 2011 Ecology report on sources of selected chemicals in the Puget Sound Basin (Ecology 2011b).

We cannot estimate the amount of PCBs currently in Washington State from partially closed applications, i.e. hydraulic fluids, heat exchange fluids, and gas pipelines. Hydraulic fluids containing PCBs were used in industrial applications that required heat and/or fire resistance. From 1929 to 1975 about 6% of PCBs produced were used for hydraulic fluids and lubricants (EPA 1997). Heat transfer fluids containing PCBs were used in industrial equipment. From 1929 to 1975 about 2% of PCBs produced were used heat transfer fluids (EPA 1997). PCB-based oils were used in gas transmission compressors. The compressors were used to move natural gas through thousands of miles of pipelines across the U.S. PCBs were also used as a fine mist into underground metal gas pipes to slow corrosion and lubricate the pipelines. PCBs remain in the pipelines until remediated, contributing to environmental releases through leaks and spills.

Closed Uses

Transformers and Large Capacitors

PCBs have not been manufactured in the US for use in transformers and capacitors since 1977. Although many PCB-containing transformers have been retired, many remain in use. The estimated lifetime of transformers may be as long as 85 years and 20 years for capacitors (Ecology 2011b). While transformers and capacitors are considered "totally enclosed" under TSCA, there are leaks and spills from such equipment until it is retired and replaced.

The size of transformers and capacitors vary and the amount of PCBs per unit also varies. Askarel transformer fluid is typically 60-70% PCB by weight. The quantity of oil per transformer unit ranges from 150-1,890 liters and weighs 235-2,932 kg, resulting in a PCB content of 141-2,052 kg per transformer (EPA 1987).

Capacitors are typically filled with nearly pure PCB oil and the largest capacitors contain as much as 35 kg PCB (Ecology 2011b). The typical large, high voltage capacitor weighs about 54 kg and contains 11 kg of PCBs (EPA 1982 proposed rule in the Federal Register).

A 1987 EPA report on sources of PCBs includes accidental release estimates from a 1982 study by the Edison Electric Institute and the Utility Solid Wastes Activity Group (EEI/USWAG).

During this study of utility industry equipment, 2.3% of large capacitors were found to have developed small leaks annually and 0.77% developed moderate leaks annually (1982 Federal Register). The study reported finding small leaks in 12% and moderate leaks in 4% of the inspected PCB transformers. The EPA used reported leakage rates for mineral oil transformers and PCB capacitors to calculate an annual PCB leakage amount from all electrical equipment (EPA 1987). Leakage rates from mineral oil transformers and PCB capacitors were applied to the estimated number of units still in use to derive an estimate for annual leakage. Using the 1982 data, annual leakage rates of 0.23 kg PCBs/unit for transformers and 0.06 kg PCBs/until for large capacitors were calculated (EPA 1987).

Estimate in Washington

The EPA maintains a transformer registry. There are 210 registered transformers with 86,322 kg of PCB oil in Washington (Appendix F). Using the lower bounds of transformers oil containing 60% PCBs, the amount of PCBs in the 86,322 kg oil is 51,793 kg PCBs. The average amount of PCBs per transformer in Washington from the registry is 247 kg PCB/transformer, which is within the EPA estimate mentioned above of 141-2.052 kg PCB/transformer.

The registry does not reflect the actual number of PCB transformers still in service and no current inventory of PCB equipment exists in the US (EPA/EC 2009). The EPA states that the database is "not particularly useful for determining the amount of PCB equipment that is remaining in service" (EPA/EC 2009). Various attempts have been made to estimate the number of units remaining in use. The Great Lakes Binational Toxics Strategy 2009 Biennial Report (EPA/EC 2009) estimates that 64,312 PCB transformers and 1,293,000 large PCB capacitors remained in use throughout the US while there are about 14,150 registered transformers in the EPA database. Scaled down from the national to the state based on 2010 population, an estimated 1,401 transformers and 28,162 large PCB capacitors remained in use in Washington in 2007.

As part of reducing PCB loads into San Francisco Bay, annual leaks from transformers and large capacitors were estimated (McKee et al. 2006). The report estimated that US transformers leak 0.05% each year. Using the amount of PCBs in transformers in Washington in the EPA Registry leads to an estimate of 43 kg. Applying this average to the number of transformers estimated from national estimates and the 0.05% rate of spills/leaks, leads to an estimate of 288 kg. The San Francisco report also estimated a leakage rate of 0.35% from large capacitors. Using the average amount of 11kg PCBs per large capacitor mentioned above, the estimated number of large capacitors in Washington based on the national estimate and the 0.35% leakage rate leads to an estimate of 1084 kg.

This results in a total annual release estimate of 30-300 kg for transformers and 1100-1700 kg for capacitors in Washington State (Table 12).

Table 12 Release estimate for transformers and capacitors

Equipment Type	Basis for estimate	Number of units	PCBs (kg)	PCB spill/leak rate (annual)	Annual PCB release (kg/yr)
Transformers	EPA registry	210		0.23 (kg/unit)	48
			51,793	0.05 %	26
	Scaled from national estimate	1,401		0.23 (kg/unit)	322
			346,047	0.05 %	173
Large Capacitors	Scaled from national estimate	28,162		0.06 (kg/unit)	1690
			309,782	0.35%	1084

There is uncertainty in the number of electrical units still in use and the older data on leakage rates may not reflect current operating conditions. The estimates do not account for spill response, thus actual amounts of PCBs released to the environment may vary. Indoor spills in particular are likely to be contained and cleaned up. Additional emissions from direct volatilization from equipment are likely, but not estimated.

Opportunities for Reduction

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Small Capacitors

Capacitors containing less than three pounds of PCB oil are considered small capacitors. Small capacitors containing PCBs have been used in a number of items including motors, appliances, and light ballasts. Small capacitors generally contain 45-270g of PCBs oil and lamp ballast capacitors contain 45-70g PCBs (EPA 1982 proposed rule in the Federal Register).

Wisconsin found submersible well pumps that contain PCB filled capacitors and in 1992 estimated that 10,000 -15,000 of their 800,000 wells contained capacitors with PCBs (Wisconsin DNR 2001). This only applies to equipment that was manufactured before 1979. Such pumps have not been identified in Washington, but Wisconsin has recommendations for owners to identify such pumps and prevent exposure.

Estimate in Washington

Several estimates have been found to indicate the number of small capacitors remaining in use. In 1992 the University of Illinois estimated that 10-25% of US household appliances contained capacitors with PCBs (Panero et al. 2005). EPA (1982) estimated that historically there were 870 million small capacitors in use throughout the US in 1977 in industrial machines and small appliances. EPA (1987) also estimated a 10% annual disposal rate in 1982. Scaling the national

estimate to Washington based on population and applying annual disposal rates of 20% and 10% yields an estimate of 12,000 to 586,000 small capacitors still in use in 2010.

Globally, one third of all PCB production may have gone into lighting ballasts (Ecology 2011b). National estimates of lamp ballasts currently in use include 300 million (US Army 2001) and 500 million (Missoula County 2010). In 1998 EPA, citing an unnamed industry source, estimated that 1 billion small lamp PCB ballasts remained in use in the US (EPA 1998). Scaling this estimate to Washington based on population and applying annual disposal rates of 20% and 10% yields an estimate of 1.7 million to 6.2 million such ballasts still in use in 2010 in Washington.

While we have some information on the number of PCB containing capacitors collected in Washington as hazardous waste or moderate risk waste, the information is not complete enough to use for estimating the number of units still in use.

A range of 12,000 to 6.2 million units remains in use in Washington State. While small capacitors may contain 45-270g PCB per unit, most of the remaining units are likely to be lamp ballasts, which typically contain 45-70g PCB per unit. For the estimate we used 57.5g PCB/unit as an average. The leakage rate is 4.2 kg/metric tons of PCBs, from the 1982 study on large capacitors (EPA 1982). This results in an estimate of 3-1,500 kg annually (Table 13).

Table 13: Small capacitors, including lamp ballasts

Equipment Type	Basis for estimate	Number of units	PCBs (kg)	PCB spill/leak rate (annual)	Annual PCB release kg/yr)
Other small capacitors	Scaled from national estimate	12,000-586,000	690-350,000	4.2 kg/metric ton	3-1500
Lamp ballasts	Scaled from national estimate	1.7-6.2 million			

There is uncertainty around both the estimate of how many small PCB capacitors remain in use and how much leaks each year. Additional emissions from direct volatilization from equipment are likely, but not estimated.

Opportunities for Reduction

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Open Uses

Caulk

PCBs were used in caulk and joint sealants to improve the flexibility, increase the resistance to erosion, and improve adherence to other building materials from the 1950s to the 1970s (Robson et al. 2010). Monsanto voluntarily stopped producing PCBs for open uses, such as caulk, in 1971 (ATSDR 2000). While the use of PCBs in open products above 50 ppm was banned in the US

effective in 1979 under TSCA, materials that contain PCBs were not required to be removed. The use of PCB containing caulk was a common practice in the 1970s and caulk formulations changed during the late 1970s (Herrick et al. 2004). The studies on PCBs in caulk have focused on buildings built from about 1950 to 1980 to include using up the existing stocks of PCB containing caulk.

Sealants with high levels of PCBs have been found at varying levels in buildings in several studies. All of the studies found congener profiles consistent with Aroclors 1248, 1254, and 1260. In general, PCBs were used at 5-30% in caulk (Priha et al. 2005). PCBs can be lost from caulk through volatilization, as well as wash-off and erosion. PCBs in caulk are associated with higher levels of PCBs in indoor air and dust, and the external soil (Priha et al. 2005, Herrick 2007, SAIC 2011). Larger amounts of PCBs may be lost during renovations or destruction. Certain removal practices can reduce the amount of PCBs released both to workers and the environment (Sundahl et al. 1999).

Herrick et al. (2004) found PCBs in schools and other buildings in the Boston area. In 13 of the 24 buildings sampled, PCBs were found at concentrations of 2 to 36,000 ppm. PCB levels in the air ranged from 111 to 393 ng/m^3 and in dust samples up to 81 ppm.

There was a nationwide comprehensive survey in Switzerland (Kohler et al. 2005). In this study, 1348 samples from concrete buildings built between 1950 and 1980 were analyzed for PCBs. Forty-eight percent of the samples contained PCBs, from < 50 ppm up to 550,000 ppm (55%).

The amount of PCBs in caulk was estimated in Toronto, Canada (Robson et al. 2010, Diamond et al. 2010). This study was based on a smaller sample size and found PCB-containing caulk in 14% of 95 buildings at concentrations of 0.57 mg/kg to 82 mg/kg. In Toronto, institutional and commercial buildings and infrastructure (e.g., bridges and parking lots) made of concrete were most likely to have PCB-containing caulk. They detected PCB in caulk in one single family detached home. As expected, they did not find PCBs in caulk in buildings built before 1945 or after 1980. Based on the number of concrete institutional and commercial buildings built between 1945 and 1980, the size of the buildings, the amount of caulk in a typical building, the percentage estimated to have caulk, and the average concentration of PCBs in caulk, the authors estimated 13 metric tons of PCBs are in caulk in Toronto. The authors further estimated that up to 9% of the PCBs in caulk had been lost via volatilization. The observed congener pattern is consistent with volatilization of lower chlorinated congeners and comparative enrichment of higher chlorinated congeners (Robson et al. 2010).

There was also a study of PCB in caulk in the San Francisco Bay area as part of implementing the TMDL (Klosterhaus et al. 2011). This report estimates PCBs in buildings and how much is released to runoff during renovation and demolition. PCBs were detected in 88% of the 25 samples from 10 buildings. The concentrations ranged up to 220,000 ppm (22%) with 40% of the samples exceeding 50 ppm. The median and range were similar to the studies in Boston and

Switzerland. The medium estimate was 10,500 kg of PCBs in caulk in existing buildings, using a similar method as was used in the Puget Sound Study (Klosterhaus et al. 2011). Information on the number of renovations and demolitions in the San Francisco Bay area each year was used to estimate that 0.04 kg PCB is released each year to stormwater from renovation and demolition. Washington does not have information on the number of commercial buildings of that age and construction type are renovated or demolished each year.

As part of the Lower Duwamish Waterway (LDW) cleanup in Seattle, Science Applications International Corporation (SAIC) investigated PCBs in old caulk and paint in the LDW (SAIC 2011). This was part of an effort to find additional sources of PCBs in the cleanup area, especially since high levels of PCBs in paint, caulk, and other building materials had been found at the former Rainier Brewery and North Boeing Field. They detected Aroclors in 8 of 17 composite samples from representative buildings with detected concentrations from 3 to 920 mg/kg. The focus was on industrial buildings from 1950-1977. As expected, they did not find PCBs in a sample from buildings built in the 1940s. Surprisingly, they reported another building in the Seattle area that was built in 1989 and contained PCBs in caulk up to 1000 mg/kg. The use of PCBs in caulk in North America has not been reported this late. The number of samples with detectable PCBs (47%) is in agreement with the larger comprehensive study in Switzerland (Kohler et al. 2005).

Estimate in Washington

The report on sources of toxic chemicals released in the Puget Sound Basin (Ecology 2011b) estimated 59 metric tons of PCBs are in building sealants in that area with about 110 kg released annually. This estimate was based on the number of existing masonry commercial buildings that were built between 1945 and 1980, the average size of those buildings and the distribution of PCB concentrations in caulk found in the more comprehensive survey by Kohler et al. (2005). This is likely to underestimate the amount of PCBs in sealants because it does not consider all uses in buildings, such as around windows, uses in residential buildings, or in other structures, such as bridges and sidewalks. The annual release estimate was based on a release rate coefficient of 0.0018/yr from long term loss rates in Robson et al. 2010.

The estimate for the Puget Sound Basin was based on detailed information about buildings in Pierce and Snohomish Counties and then scaled up to the rest of the study area by population. The estimated volume of masonry buildings built from 1945 to 1980 in Pierce and Snohomish Counties was 21,941,562 m^3. To estimate PCBs in caulk for the state we scaled up the volume of masonry commercial buildings that were build between 1945 and 1980 by population, leading to an estimate of 97,702,645 m^3 with 5,373,645 kg of caulk for the state.

The large study in Switzerland (Kohler et al. 2005) found 48% of the targeted buildings had PCB containing sealants. Applying this to the state estimate on sealants, leads to 2,573,976 kg of PCB containing sealants. The PCB concentration in ranges from Kohler et al. (2005) were applied to

the estimate PCB containing sealants in Washington, yielding an estimate of 87 metric tons of PCBs in sealants in Washington with 157 kg released annually (Table 14).

Table 14: Estimates from caulk

sealant quantity (kg)	sealants with PCBs (kg)	PCB conc bin (mg/kg)	bin mid point	% for each bin	PCB quantity (kg)	annnual releases (kg)
5,373,645	2,573,976	20-50	35	0.121	11	
		50-100	75	0.0772	15	
		100-1,000	550	0.1899	269	
		1,000-10,000	5,500	0.1815	2,569	
		10,000-100,000	55,000	0.2316	32,787	
		>100,000	100,000	0.2003	51,557	
Total					87,208	157

In addition, PCBs are released into the environment during renovation and demolition of buildings that contain PCBs in caulk and other building materials. In order to estimate this we need to know how many buildings of that age and construction type are demolished or renovated in the state, which we do not know.

Opportunities for Reduction

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Inadvertent generation

PCBs are no longer intentionally manufactured in the U.S. and the manufacture, processing, and distribution in commerce of PCBs at concentrations of 50 ppm or greater is not allowed. EPA promulgated a rule under TSCA in 1984 for inadvertent generation of PCBs that are not in closed or controlled manufacturing processes (49 FR 28172). The concentration of inadvertently generated PCBs in products must have an annual average of < 25 ppm, with a maximum of 50 ppm. In addition, EPA required manufacturers with processes inadvertently generating PCBs and importers of products containing inadvertently generated PCBs to report to EPA any process or import for which the PCB concentration is greater than 2 mg/kg for any resolvable PCB gas chromatographic peak. More details on TSCA are in the section on Regulations.

As part of this rulemaking on inadvertently generated PCBs, EPA generated a list of 200 chemical processes with a potential for generating PCBs (Appendix D) and narrowed it to 70 with a high potential to inadvertently generate PCBs. The list does not include every process that inadvertently generates PCBs and not everything on the list inadvertently generates PCBs. In general, PCBs can be produced when chlorine and carbon are present with elevated temperatures or catalysts.

The final rule also includes an estimated annual production of inadvertently generated PCBs of 100,000 lbs (45,400 kg). Scaled to population, Washington's share of that would be about 900 kg a year. Only 11% of the PCBs were estimated to enter products, or 100 kg annually in Washington. As the economy has grown over the last 30 years, the amount of inadvertently generated PCBs may also have grown. This was an estimate from a consensus proposal from the Environmental Defense Fund, Natural Resources Defense Council, and Chemical Manufacturers Association (now known as the American Chemistry Council) that included all inadvertent generation of PCBs, without being broken down into how much came from each process. Products that are mentioned include paints, printing inks, agricultural chemicals, plastic materials and detergent bars. The 1982 economic analysis for this rule mentions 135 manufacturing processes that generate PCBs at less than 50 ppm from a Chemical Manufacturers Association survey. The economic analysis also includes a list from EPA of about 20 "end-products of manufacturing processes in which PCBs are incidentally generated."

In this rule on inadvertent production, EPA specifically mentioned surfactants as the component of detergent bars that is likely to contain PCBs. EPA also mentioned PCBs are likely to be in surfactants in skin lotions and creams that are regulated by the FDA. We have no estimate for how many PCBs are inadvertently produced in surfactant.

Pigments and dyes

More details on generation of PCBs during manufacturing are in the earlier section on Chemistry. PCBs are known to be inadvertently generated in certain pigments and dyes, including diarylides (yellow and orange), naphtharylamides (oranges and reds), phthalocyanines (blue), and basic dye complex pigments (reds, violets, blues and greens) (Christie, 2013). PCB-11 is thought to be primarily from pigment production and not from legacy uses of Aroclors (Hu and Hornbuckle 2010, Guo 2013).

Hu and Hornbuckle (2010) found PCBs in azo and phthalocyanine pigments, including PCB-11 and higher chlorinated PCBs 206-209. Previously PCB-209 was only thought to be found in ferric oxide as a by-product of titanium dioxide production (Panero 2005). PCB-11 and PCB-209 have been found in Washington's environment and animals (Ecology EIM database).

Higher chlorinated PCBs are inadvertently generated during the production of the inorganic pigment titanium dioxide using the chlorine process (UNEP 2007). We were unable to locate estimates on the amount of PCB inadvertently generated in this process.

Estimate in Washington

While different researchers have detected PCBs in pigments and consumer products, we don't have a good estimate for how much is released in Washington each year. Panero et al. (2005) estimated PCB-11 represents 5-20% of the PCBs entering NY harbor. Jia Guo (2013) estimated

that between 5 and 7800 kg[10] of PCB-11 are produced worldwide each year from diarylide yellow in 2006. The US market consumes approximately 20% of global organic pigments (Guo 2013). Washington is approximately 2% of the US population, which leads to an estimate for Washington's share of PCB-11 from yellow pigment of 0.02 and 31 kg per year. This is the amount of PCB-11 in products, with an unknown amount entering the environment.

In addition to PCBs in pigments and dyes in nonpoint sources such as consumer goods, there are also permitted releases in Washington. Inland Empire Paper Company and Ponderay Newsprint Company discharge PCBs into Washington waterways. In 2012 the average PCB concentrations in their discharge were 2,520 and 1079 pg/L, respectively. Based on flow rate, the estimated PCB loading for these two facilities is 28 g per year, with 3.8 g being PCB-11.

Opportunities for Reduction

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Commercial and industrial releases

Toxics Release Inventory (TRI)

The federal Toxics Release Inventory (TRI) includes permitted estimated releases from facilities that discharge from certain industries. The TRI database is authorized under the federal Emergency Planning and Community Right to Know Act to aid in community planning in case of an emergency and to generally inform the public about releases of toxic chemicals.

PCBs are subject to reporting and listed with the general CAS number 1336-36-3 for all PCBs. Because PCBs are PBTs, there is a lower level for reporting and the reporting threshold is 10 lbs.

There are only two reporters of PCBs in Washington to the TRI. Burlington Environmental in King County and Perma-Fix Northwest in Benton County are both hazardous waste treatment and disposal companies. From 2007-2011 they reported an average off-site waste disposal of 25,000 pounds (Table 15).

[10] Jia Guo is an author on an earlier paper (Rodenburg et al. 2010) that estimated worldwide production of PCB 11 from diarylide yellow pigment production at 1.5 t in 2006. This estimate was revised in Guo 2013.

Table 15: Table of reports from 2007-2011

Year	Reporter	Offsite waste reported (pounds)
2007	BURLINGTON ENVIRONMENTAL INC	485
2007	PERMA-FIX NORTHWEST RICHLAND INC.	14,163
2008	BURLINGTON ENVIRONMENTAL INC	389
2008	PERMA-FIX NORTHWEST RICHLAND INC	710
2009	BURLINGTON ENVIRONMENTAL INC	565
2009	PERMA-FIX NORTHWEST RICHLAND INC	11,869
2010	BURLINGTON ENVIRONMENTAL INC	1,081
2010	PERMA-FIX NORTHWEST RICHLAND INC	61,554
2011	BURLINGTON ENVIRONMENTAL LLC	1,000
2011	PERMA-FIX NORTHWEST RICHLAND INC	31,543

Opportunities for Reduction

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National Emissions Inventory (NEI)

The National Emissions Inventory (NEI) is a comprehensive and detailed estimate of air emissions of air pollutants from all air emissions sources. The NEI is prepared every three years by the EPA based primarily upon emission estimates and emission model inputs provided by State, Local, and Tribal air agencies for sources in their jurisdictions, and supplemented by data developed by the EPA. According to the most recent NEI for 2008, there were 439 lbs (199 kg) of PCBs released to the air from residential waste burning and 0.8 lbs (0.4 kg) released from commercial marine vessels. In addition to these sources, the Spokane Regional Clean Air Agency reported about 1 lb of PCB emitted from the Waste to Energy facility in 2011.

To obtain emission estimates for residential waste burning, EPA applies emission factors to an assumed mass of residential waste burned at the county level across the country. Some of the key assumptions are that residential waste burning only occurs in rural counties, and roughly 28% of the waste generated in these counties is burned in backyard burn barrels. This estimate is

very uncertain, but can only be improved with location specific information regarding local compliance with residential waste burning rules.

Opportunities for Reduction

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Summary

Table 16 below summaries the estimates for uses and sources in Washington State found in this section.

Table 16: Summary of Uses and Releases for Washington State

Source		reservoir (metric tons)	annual releases (kg/yr)
Closed Uses			
	transformers	86-580	30-300
	large capacitors	310	1100-1700
	small capacitors	1-350	3-1,500
	other closed uses		unknown
Partially closed uses			unknown
Open uses	caulk	87	160
	other open uses		unknown
Current generation			
	pigments and dyes		0.02-31
	other inadvertent generation		900
	residential waste burning		199
	commercial marine vehicles		0.4

Pathways and Environmental Fate

Current PCB levels represent both historical and ongoing loadings and cycling among environmental compartments.

Unfortunately, we don't know where much of the PCBs that were produced are currently located. For example, small capacitors were a large use of PCBs, but since they were used in unregulated appliances, we don't know how many are still in appliances in people's homes, how many were disposed of in municipal waste landfills (and how much PCBs have since leaked out of those landfills or volatilized), and how many were disposed of outside of landfills.

Pathways

Stormwater

Assessments of both Puget Sound (Ecology 2011a) and the Spokane River (Ecology 2011c) have found the largest pathway for PCBs to reach the aquatic environment is stormwater. Publically owned treatment works (POTWs) were a smaller pathway in both studies. Air deposition was the second largest pathway in the Puget Sound study, while it was not assessed in the Spokane River study.

Salmon

Pacific salmon returning to spawn are another pathway for PCBs to enter Washington. Salmon have complex life histories and long-range migrations for feeding. The accumulation of PCBs in fish depends on many things including contaminated habitats, which food they eat and the levels of PCBs in food, lipid level, and age. Chinook salmon are 3-5 times more contaminated than coastal Chinook (West 2011). Most (99%) of the final weight of adult Chinook is achieved in salt water, both ocean and Puget Sound, and >96% of the PCBs in adult Chinook accumulated during their marine life history phase (O'Neill and West 2009). Sandie O'Neill estimated that 0.265 kg/yr PCBs enters Washington through this pathway (Ecology (PS Assessment Report) 2011). This estimate comes from whole body PCB concentrations for five species of Pacific salmon and their estimated biomass.

Motor oil

The City of Spokane reported measurements of PCBs in motor oil in their 2013 Adaptive Management Plan for Reducing PCBs in Stormwater Discharges from the Wastewater Management Department. The concentration of total PCBs in four samples of motor oil ranged from 14 to 116 ppb with an average of 54 ppb. Using this average concentration and the estimates of drips and leaks from motor vehicles and improper disposal of used motor oil in

Washington as in the PAH CAP (Ecology 2012a) gives an estimate of 0.6 kg of PCBs per year from motor oil.

PCBs are not created in motor oil, so motoro oil is not considered a source here. The PCBs in motor oil are likely contamination from an unknown source. The homologue pattern is different from the PCBs found in sediments from stormwater catch basins in Spokane, with a much larger percentage of mono and dichlorobiphenyls and smaller percentage of higher chlorinated congeners. Of course, the congeners in sediment have been weathered and would no longer match the profile of the original source. PCB 11 was not the major dichlorpbiphenyl detected.

Environmental Partitioning

The estimates we do have for the fate of all the PCBs produced are not current. Newer publications cite estimates in earlier publications. The estimates vary, but they agree that much of the PCBs that were produced up to 1977 are still in use. This is a large reservoir of PCBs that are slowly leaking out into the environment. For transformers in particular, we know that much of the PCBs in transformers have been removed since these estimates were made. We just don't know how much. Transformers and capacitors were the largest use of PCBs and have been targeted for PCB removal.

In 1997 EPA estimated the inventory of PCBs as of 1977 as "Of the 700,000 [short] tons of PCBs produced, 150,000 tons had been landfilled; 75,000 tons had entered the air, water, and soil; 25,000 tons had been incinerated; and 375,000 tons remained in electrical equipment. The remainder, approximately 75,000 tons, had been exported."

Converting this estimate of short tons into metric tons leads to:

- 636,000 Produced (1927-1976)
- 568,000 Used (68,000 exported)
- 340,000 Remaining in use (60%)
- 228,000 Disposal/environment
- 132,000 Landfill (23%)
- 68,000 Environmental media (12%)
- 28,000 Incinerated (5%)

Keeler (1993) had similar estimates for the status of PCBs in the US as of 1982. The Canadian government estimated PCBs in Canada as of 1992 (CCME 1995) and Tanabe (1988) estimated similar percentages worldwide in 1985 (Table 17). All of these estimates show a large percentage of PCBs still in use and a small percentage destroyed by incineration. Unfortunately, we do not have more current estimates of PCB stocks and many of the PCBs that were in use at the time of these estimates have been taken out of use for disposal.

Table 17: Estimates for the status of PCBs (in metric tons)

Status	US 1977 (EPA 1997)	US 1982 (Keeler et al 1993)	Canada 1992 (CCME 1995)	Global 1985 (Tanabe 1988)
Produced	636,000	640,000		1,200,000
Used	538,000	582,000 (91%)	40,000	1,200,000
Remaining in Use	340,000 (40%)	346,000 (54%)	15,000 (38%)	780,000 (65%)
Landfill/Storage	132,000 (23%)	134,000 (21%)	6000 (15%)	
Environment	68,000 (12%)	70,000 (11%)	12,400 (31%)	370,000 (31%)
Incinerated	28,000 (5%)	19,000 (3%)	6,200 (16%)	50,000 (4%)

Tanabe (1988) also broke down the global PCBs in the environment into different media (Table 18). Not shown in Table 18 is that the largest global reservoir of PCBs is ocean water (while PCBs are not very soluble in water, the vast quantities of oceans worldwide hold more than half of the PCBs in the environment). Table 18 only includes estimates from the terrestrial and coastal waters and not ocean water.

Table 18: Global PCBs from Tanabe 1988

	PCB loads (metric tons)	percent
terrestrial and coastal		
air	500	0.35
river and lakewater	3,500	2.45
seawater	2,400	1.68
soil	2,400	1.68
sediment	130,000	90.85
biota	4,300	3.00
total	143,100	100

The estimates from Tanabe 1988 in Table 18 substantially agree with the model for Puget Sound (Ecology 2009b). This found approx 97% of the total mass of PCBs currently in the aquatic ecosystem of Puget Sound is contained in the active sediment layer (top 10 cm), about <1% is stored in the water column, and about <3% is stored in the biota. O'Neill and West (2007) estimated PCBs in biota using PCB concentrations and biomass. Their total estimate is less than 40 kg of PCBs in Puget Sound biota.

Puget Sound Example

We have more information about Puget Sound compared to the rest of the state and can use that example to illustrate the relative amounts of PCBs in the environment, in legacy products, coming from legacy products each year, and being inadvertently produced in new products each year. These estimates come from the Control of Toxic Chemicals in Puget Sound reports on sources (Ecology 2011b) and models (Ecology 2009b), and WDFW (O'Neill and West 2007).

Less than 1500 kg PCBs is in the biota cycling

- 1440 kg Sediment
- 10 kg Water column
- <40 kg Biota

Tons of PCBs are in legacy products

- 12,000- 400,000 kg Transformers
- 200,000 kg Large capacitors
- 400-300,000 kg Small capacitors
- 60,000 kg Caulk

About one ton of PCBs are released from the legacy products each year

- 130 kg Transformers
- 1,100 kg Large capacitors
- 500 kg Small capacitors
- 110 kg Caulk

Some PCBs are inadvertently generated each year

- 630 kg

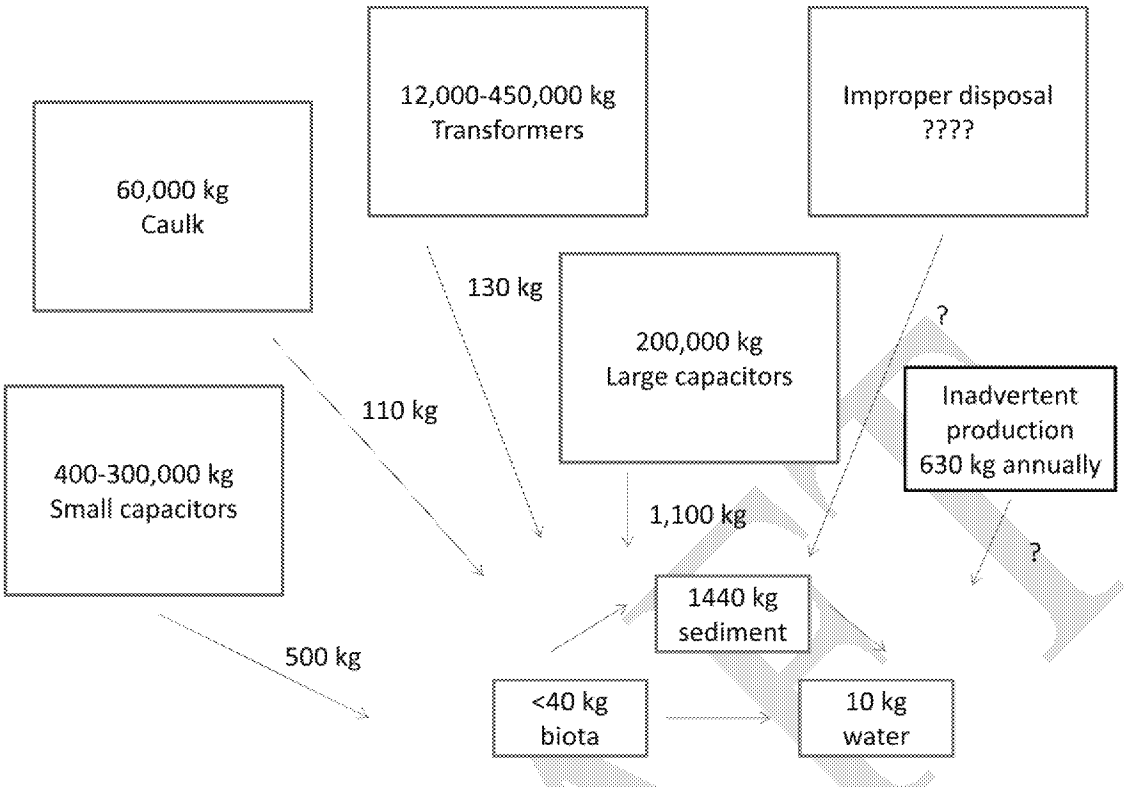

Figure 12: PCBs in Puget Sound

The red boxes are the estimated reservoirs of legacy PCBs. The blue boxes are estimated amounts of PCBs in environmental media and biota. The black box is estimated inadvertent production of new PCBs. The blue arrows are estimated releases and cycling.

Wildlife Health

Introduction

PCBs have similar effects in wildlife, people, and model organisms used to study people in laboratory experiments. Thus, this section and the section on Human Health have many similarities, although the health effects that are measured often differ between people and wildlife. Negative effects of PCBs in wildlife are of concern because of the effects on animal populations, because animal populations may be sentinels for human health, and because we are also part of the food chain and are exposed to PCBs through our diet.

PCBs can be acutely toxic to wildlife, but most of the considerations are for chronic exposure. Data are most prevalent on mortality, reproduction, development, and endocrine effects. The induction of enzymes and genes are also used to assay PCB effects. Other endpoints include cancer, immunological, neurological/behavioral, and hepatic effects. Experimental studies are often performed for certain endpoints because of correlations seen in the field with PCB levels and specific endpoints.

Wildlife is exposed to varied mixtures of PCBs in the environment. Different PCB congeners behave differently in the environment; they preferentially partition into different media and they are preferentially degraded and bioaccumulated. In addition, there are multiple sources of PCBs that contain different mixtures of congeners that release PCBs into the environment. Therefore, the actual environmental conditions are different than many of the laboratory studies on specific Aroclor mixtures or specific congeners.

Sensitivity to PCBs varies among species and within species. For example, fish are most susceptible in early life stages. Inter-species variation is also due to different lipid levels, because PCBs are lipophilic and sequestered in lipid-rich tissues. PCBs are biomagnified up the food chain, so organisms on higher trophic levels have higher concentrations of PCBs. There are other differences among species that affect PCB metabolism. For example, invertebrates lack the enzyme systems that react with dioxin-like PCBs.

Although environmental levels of PCBs have declined substantially since they first came under regulation in the 1970s, the rate of decline has slowed in recent years and significant contamination continues to be widespread in Washington State. Due to global atmospheric transport and internal cycling, success in achieving PCB reductions in Washington's environment is likely to be modest outside of areas with significant contamination

Puget Sound is a regional hot spot for PCBs compared to the Pacific coast and British Columbia. Within Puget Sound, the most contaminated areas are in the main basin, especially Seattle's Elliott Bay and Tacoma's Commencement Bay, and, to a lesser extent, Everett Harbor and the

Bainbridge Basin. Puget Sound's food web, from plankton on up to harbor seals and killer whales, has significant PCB contamination. Herring and Chinook salmon are notably affected. Hot spots for PCBs are also present in Washington rivers and lakes. Based on PCB levels in resident fish species, major waterbodies of most concern are the Wenatchee River, Lake Washington, the Columbia River, and the Spokane River.

Health effects in wildlife

Table 19 (from ATSDR 2000) summarizes PCB effects seen in laboratory experiments and field studies with wildlife species. Most species have mortality at high doses.

Adverse effects in birds include:

- Reduced egg hatchability and live births
- Reduced avoidance response
- Altered mating, reproductive, parenting, and nesting behavior
- Suppression of immune response

Adverse effects in fish include:

- Reduced hatchability in eggs
- Altered muscle coordination
- Depressed immune system with increased susceptibility to infections
- Loss of fins and tails in flatfish

Adverse effects in mammals include:

- Loss of embryos and fetuses and reduced live births
- Alteration in the immune system in mink, sea lions, and seals
- Tumors and deformities of skeleton and skin in seals

Table 19: PCB Hazards in Wildlife with references noted in original (ATSDR 2000 Table 3-6)

Adverse effect	Wild mammals				Birds			Reptiles	Amphibians		Fish	
	Primate	Mustelid	Cetacean, pinniped	Other	Piscivore	Galliform	Other	Turtle	Frog	Toad	Freshwater	Marine
Mortality	OE1	OE1		OE3	OE3	OE1	OE3		OE1	OE1	OE1	OE3
		OE3				OE3			OE3	OE3	OE2	
		OE4									OE3	
Systemic effects												
Respiratory		OE4				OE3						OE3
Cardiovascular		OE3	OC4			OE3						
		OE4										
Gastrointestinal	OE1	OE1	OC4			OE3						
	OE3											
Hematological		OE4									OE3	
Musculo-skeletal						OE3					OE3	
Hepatic	OE3	OE1			OE3	OE1	OE1				OE3	OE3
		OE3				OE2	OE3					
		OE4				OE3						
		OE5				OE5						
Renal		OE4	OC4			OE3					OE3	
Endocrine	OE3	OE3	OE3		OE3	OE3	OE1				OE3	OE3
		OE4	OE4		OC4		OE3					
		OE5	OC4									
Dermal/ocular	OE1	OE3	OC4								OE3	
	OE3											
Body weight	OE1	OE1				OE2	OE1			OE3	OE3	
	OE3	OE3										
Metabolic		OE5					OE1		OE2		OE3	

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Adverse effect	Wild mammals				Birds			Reptiles	Amphibians		Fish	
	Primate	Mustelid	Cetacean, pinniped	Other	Piscivore	Galliform	Other	Turtle	Frog	Toad	Freshwater	Marine
Enzyme induction		OE1				OE1	OE1				OE1	OC4
		OE3				OE2	OE2				OE3	
		OE4				OE3	OE3					
		OE5										
Blood chemistry	OE1	OE5				OE3	OE1				OE3	
Immunological/ lymphorecticular	OE1	OE4	OE4		OC4	OE1	OE1				OE3	OE3
	OE3		OC4			OE3	OE3					
Neurological/ behavioral	OE2	OE2		OE3		OE3	OE3				OE2	OE3
	OE3	OE4									OE3	
Reproductive	OE3	OE1	OC4	OE3	OC4	OE3	OE1	OC4			OE3	OE3
		OE3	OE4				OE3				OC4	OC4
		OE4										
		OE5										
		OC4										
Developmental	OE3	OE3		OE3	OE1	OE1		OE4	OE1	OE1	OE3	
		OE4			OC1	OE3			OE3	OE3	OC4	
					OC4							
Egg shell					OC4	OE3	OE3					
							OC4					
Genotoxic							OE3					

O= observed effect E= experimental observation C= correlational field observation
1 = dioxin-like PCB congener (AhR binder; planar; chlorine para-substituted and non- or mono-*ortho*-substituted)
2 = non-dioxin-like PCB congener (poorly binds to AhR; non-planar; chlorine di-, tri-, or quatro-*ortho*-substituted)
3 = commercial PCB mixture (e.g., Aroclor 1016)
4 = "weathered" (i.e., environmentally degraded and/or metabolized) PCB mixture, usually in combination with other chemicals (e.g., PCBs in wild-caught fish)
5 = unspecified PCB

Examples of major endpoints

Reproduction and development

PCBs affect reproduction and development in different species. Minks are particularly sensitive to the reproductive effects of PCBs (Eisler 1986). Farm-raised mink fed a diet of PCB-contaminated fish from the upper Hudson River at the same levels wild mink are exposed to PCBs in food, showed effects on reproduction and offspring growth and mortality (Bursian et al, 2013). Females with higher levels of PCBs had fewer live kits per litter. Kit mortality decreased over time, with no kits surviving in the animals fed higher levels of PCBs. The surviving kits also had lower body masses after 6 weeks. The effects on reproductive performance were similar to those seen in earlier studies on mink fed contaminated fish from Saginaw Bay (Heaton et al. 1995a).

Immune System

PCBs are linked to increased disease susceptibility in several species. Captive harbor seals had negative effects on their immune system after being fed PCB-contaminated herring, as assayed by immune cell function and response (Ross et al. 1996). This research was undertaken to understand factors contributing to virus-caused mass mortalities of marine mammals, especially when attributed to a virus that does not always cause mass mortalities. The results suggest higher levels of PCBs contribute to higher virus-caused mortality.

Cancer

PCBs have been shown to cause cancer in laboratory animals (ATSDR 2000) and are considered to be probable human carcinogens by EPA. PCBs are thought to cause cancer indirectly, rather than by direct alterations to DNA.

Cancer is less well studied in wild populations compared to laboratory species, partly due to lower incidence. However, beluga whales in the St. Lawrence estuary and Hudson Bay have been found to have a high incidence of cancers and high levels of PCBs (Mikaelian et al, 2003). There is also evidence linking cancer in St. Lawrence estuary belugas to PAHs from nearby point sources (Martineau et al 2002), illustrating the difficulties in pointing to a specific group of chemicals in these marine mammals with many different industrial contaminants. PCB levels in California sea lions have also been found to be significantly associated with death from cancer (Ylitalo et al. 2005).

Mechanisms of action

Endocrine

PCBs interfere with estrogen and thyroid hormone levels. Studies on PCB endocrine disruption have been done in the laboratory with model animals and cell cultures (see section on Human Health). The endocrine system regulates all biological processes, although endocrine disruption

is often used just to refer to the disruption of thyroid hormones and the sex hormones estrogen and androgen. These hormones are important for growth and development, especially of the brain and nervous system and reproductive systems. While hormones are important throughout the life cycle, they are particularly important during fetal development. Hormones are signaling molecules that function at low levels, and compounds that either mimic or block natural hormones may have effects at low levels.

Ah-receptor dependent

Similar to dioxins, non-ortho (co-planar) and mono-ortho PCBs can bind to the aryl hydrocarbon (Ah) receptor. Subsequent to binding of the Ah receptor, there are changes in gene expression (e.g., induction of cytochrome p450 CYP1A1/1A2) leading to toxic responses. Induction varies by degree and pattern of chlorines and is the basis for the World Health Organization (WHO) toxic equivalency factors (TEFs) for dioxins and dioxin-like PCB congeners. These have been reviewed and modified several times. In 2005 WHO updated the TEFs for humans and mammals to replace the 1998 values (Van den Berg et al. 2006, see Table 25 in the Human Health Section). The adverse effects for these compounds are mediated through the Ah receptor and the relative potencies are compared to 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD). Consensus TEFs for wildlife were developed in 1998 (Van den Berg et al, 1998). The WHO working group harmonized the TEFs across different taxa as much as they could, but there are large differences in responses among different taxa.

Table 20: WHO TEFs for fish and birds (Van den Berg et al. 1998)

Type	Congener	TEFs	
		Fish	Birds
Co-planar PCBs	3,3',4,4'-TCB (77)	0.0001	0.05
	3,4,4',5-TCB (81)	0.0005	0.1
	3,3',4,4'-5-PeCB (126)	0.005	0.1
	3,3',4,4',5,5'-HxCB (169)	0.00005	0.001
Mono-ortho PCBs	2,3,3',4,4'-PeCB (105)	<0.000005	0.0001
	2,3,4,4',5-PeCB (114)	<0.000005	0.0001
	2,3',4,4',5-PeCB (118)	<0.000005	0.00001
	2',3,4,4',5-PeCB (123)	<0.000005	0.00001
	2,3,3',4,4',5-HxCB (156)	<0.000005	0.001
	2,3,3',4,4',5'- HxCB (157)	<0.000005	0.0001
	2,3',4,4',5,5'- HxCB (167)	<0.000005	0.00001
	2,3, 3',4,4',5,5'- HpCB (189)	<0.000005	0.00001

PCBs in Washington's Environment

Air and Soil

Due to long-range global atmospheric transport, PCBs are present in all parts of the environment. Most of the PCBs in air come from volatilization of PCB-contaminated soil and surface water. In the atmosphere, PCBs are primarily associated with the gaseous phase; approximately 10% is adsorbed to particulates, especially the higher chlorinated forms. Less chlorinated compounds travel farther than highly chlorinated compounds, which tend to stay closer to the source of contamination. Wet and dry atmospheric deposition is, in turn, the dominant source of PCBs to most soil and water surfaces. The cycle of these persistent compounds like PCBs depositing onto soil and then revolatilizing back into air is often referred to as the grasshopper effect.

PCB levels in the atmosphere have been decreasing slowly since the late 1970s when EPA began restricting their use (EPA Integrated Atmospheric Deposition Network http://www.epa.gov/glnpo/glindicators/air/airb.html; Venier and Hites, 2010; ASTDR, 2000). Due to residual sources in the U.S. and long-range transport from other countries, PCB levels in air may be plateauing.

Air in rural and remote locations has lower PCB levels than urban air, which is a source to nearby environments. Nationally, average total PCB concentrations at background locations are in the approximate range of one to several hundred pg/m^3 (Hornbuckle and Robertson, 2010). In contrast, concentrations near Lake Superior in the 1970s were well over 1,000 pg/m^3 due to influences from upstate New York and the East Coast (EPA Integrated Atmospheric Deposition Network)

The limited data available for PCBs in Washington's air has been from measurements of flux rates to water and land surfaces ($ng/m^2/day$) rather than mass per unit volume. In 2008, Brandenberger et al. (Ecology 2010d) recorded PCB fluxes to the Puget Sound basin at seven stations from Nisqually River to Padilla Bay. The median flux across all stations and rain events was 0.51 $ng/m^2/day$. Similar results were obtained for most areas, except Tacoma's Commencement Bay had a median of 1.8 $ng/m^2/day$. Brandenberger et al. concluded that PCB deposition rates to the Puget Sound basin were similar to background sites in New Jersey (0.82 $ng/m^2/day$; 1999-2000), but lower than Chesapeake Bay (9.0 $ng/m^2/day$; 1990-1991) and Jersey City, NJ (11 $ng/m^2/day$; 1999). A King County effort to quantify atmospheric deposition of chemical contaminants to the Lower Duwamish Waterway in 2005-2007 was hampered by poor detection limits for PCBs (Tiffany 2008). Field work for a new air deposition study in the Lower Duwamish was recently completed (King County 2011).

The Western Airborne Contaminants Assessment Project for national parks in the western U.S. included Mount Rainier, Olympic, and North Cascades parks (Landers et al. 2008). The results,

however, are of limited use for present purposes in that only eight PCB compounds were analyzed and detection frequency was low.

Meijer et al. (2003) estimated that the contemporary PCB burden in background soils is about 2% of the known production volume. PCB levels in U.S. background soils generally average from several hundred to several thousand pptr dry weight (Hornbuckle and Robertson, 2010). An EPA nation-wide survey of soil at 27 remote or rural sites in 2003 put the average total PCB concentration at 3,089 pptr (EPA, 2007). The single Washington site sampled during the study – Lake Ozette on the northwest coast – had 2,419 pptr.

With the exception of site-specific determinations for contaminated sites, the PCB background in Washington's marine and freshwater environment, as discussed below.

Marine and Fresh Waters

Historical vs. Recent Trends

PCB levels in Washington's marine and fresh waters have decreased substantially since peaking in the 1970s. This has been attributed to EPA's restrictions and bans on PCBs in the late 1970s and early 1980s, similar actions in Canada and other countries, contaminated site cleanups, improved wastewater treatment, loses through volatilization and metabolism of lighter compounds, and deep burial in aquatic sediments.

Although historical declines have been documented, there are components of Washington's marine and freshwater ecosystems where a decreasing trend is no longer evident. In most cases, the time-trend for PCBs can be characterized by an initial rapid decline after the ban, followed by a slowing and, ultimately, low to negligible rate of decrease over recent years, waterbodies benefitting from cleanups being a notable exception. Current PCB levels continue to be a concern for the health of fish, wildlife, and humans in Washington.

The effect of the 1970s and 1980s regulations can be clearly seen in age-dated sediment cores from Puget Sound and Lake Washington (Figure 13). A rapid increase in concentrations occurred in both Puget Sound and Lake Washington into the mid-1970s, reaching 35 ppb and 250 ppb, respectively, in sediments at these two locations. Concentrations in the recent past declined to around 10 to 20 ppb. (Detections shown prior to the mid-1930s when PCBs were first introduced are analytical noise.) A sediment core from Lake Spokane (lower Spokane River) in eastern Washington showed a similar steep decline in the 1960s and 1970s, followed by a gradual reduction over a 20-year period from approximately 1980 to 2000 similar to what was observed in Lake Washington (Ecology 2011c).

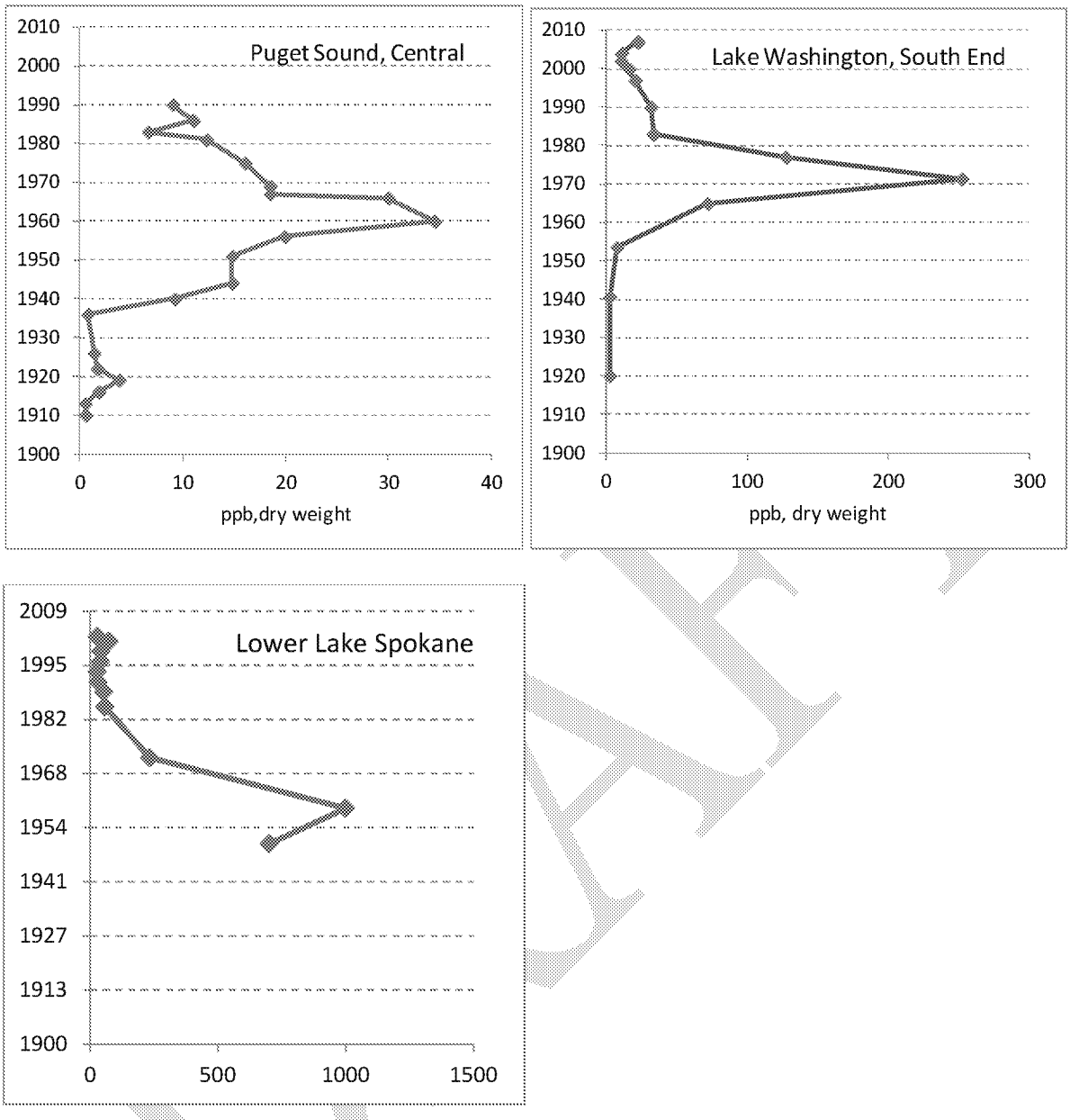

Figure 13: Total PCBs in Age-Dated Sediment Cores from Puget Sound, Lake Washington, and Lake Spokane

NOAA's Mussel Watch has monitored PCBs in marine mussels from the mouth of the Columbia River to Puget Sound since 1986. Results show that PCBs have been declining slowly, although somewhat erratically, in Washington's marine waters (Figure 14). After a steep decline in the mid-1980s, there have been two spikes of unknown origin, most obvious at the regional hot spot: Four-mile Rock in Elliott Bay. PCB levels in Puget Sound mussels remain well above national median concentrations (Mearns, 2013, O'Connor and Lauenstein, 2006).

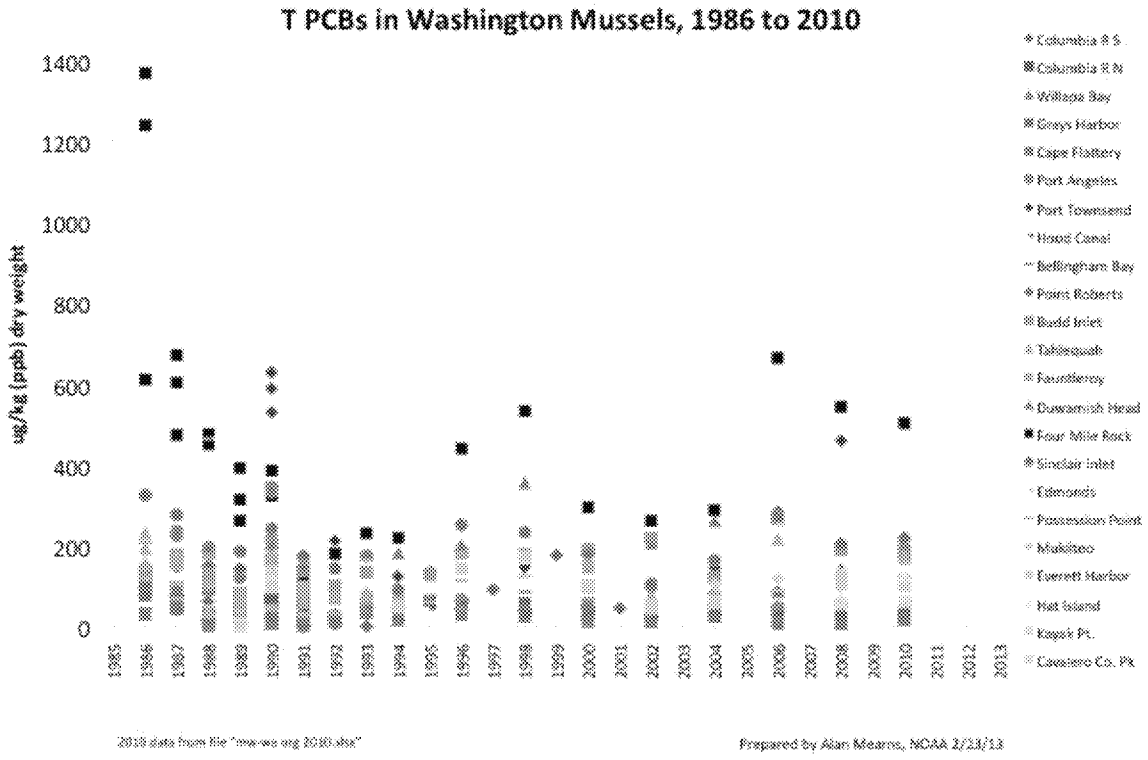

Figure 14: Total PCB Concentrations in Marine Mussels from Columbia River to Puget Sound: 1986 – 2010 (Data from NOAA National Mussel Watch Program, prepared by Alan J. Mearns, NOAA, Seattle)

Compared to historical levels, PCBs have declined in Puget Sound harbor seals (1972 to 1997) and killer whales (1993-1995 vs. 2004-2006) that inhabit or transit Puget Sound (Calamabokidis et al., 1999, Krahn et al. 2007, Hickie et al., 2007). Despite these declines, PCB-associated health impacts are observed in seals from this region (Strait of Georgia) and most Southern Resident killer whales exceed health effects thresholds for PCB residues (Cullon et al., 2009, Hickie, et al., 2007, Krahn et al., 2009). The PCB decline in these animals has been slowed by continued atmospheric delivery of PCBs from other parts of the world and internal cycling (Johannessen et al., 2008). Figure 15 shows the PCB changes observed in the blubber of South Puget Sound harbor seals up until 1997.

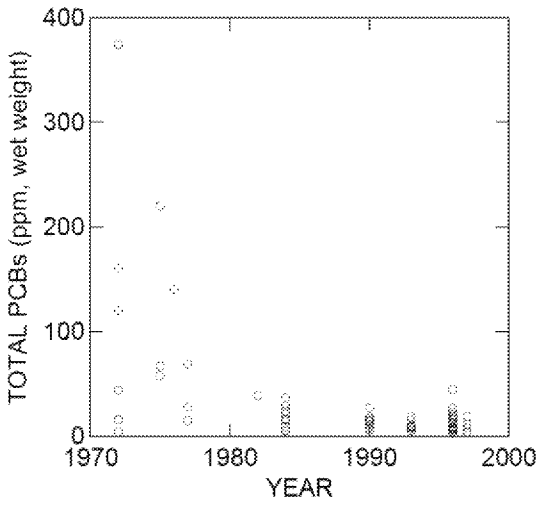

Figure 15: Historical Decline in PCB Levels among South Puget Sound Harbor Seals: Blubber Samples 1972-1991 (Calambokidis, 1999)

Monitoring by the Washington Department of Fish and Wildlife (WDFW) for the Puget Sound Estuary Monitoring Program (PSEMP) gives a mixed picture of PCB time-trends in edible tissues of marine fish (West, 2011, 2013; West et al. 2011). Levels have declined in coho salmon from central Puget Sound, but only until the 1990s. Trend data do not exist for Chinook salmon. There is no evidence of a PCB decline in four stocks of Puget Sound herring. English sole from all urban and non-urban monitoring locations except Sinclair Inlet show no significant change in PCB concentrations over the past 20 years (Figure 16). There is some evidence of improvement in Sinclair Inlet in recent years, which has been attributed to reduced stormwater loading, and dredging and capping of contaminated sediments in 2000-2001 (O'Neill et al., 2011). Sole are a bottom-living species that demonstrate the link between PCBs in sediment and biota.

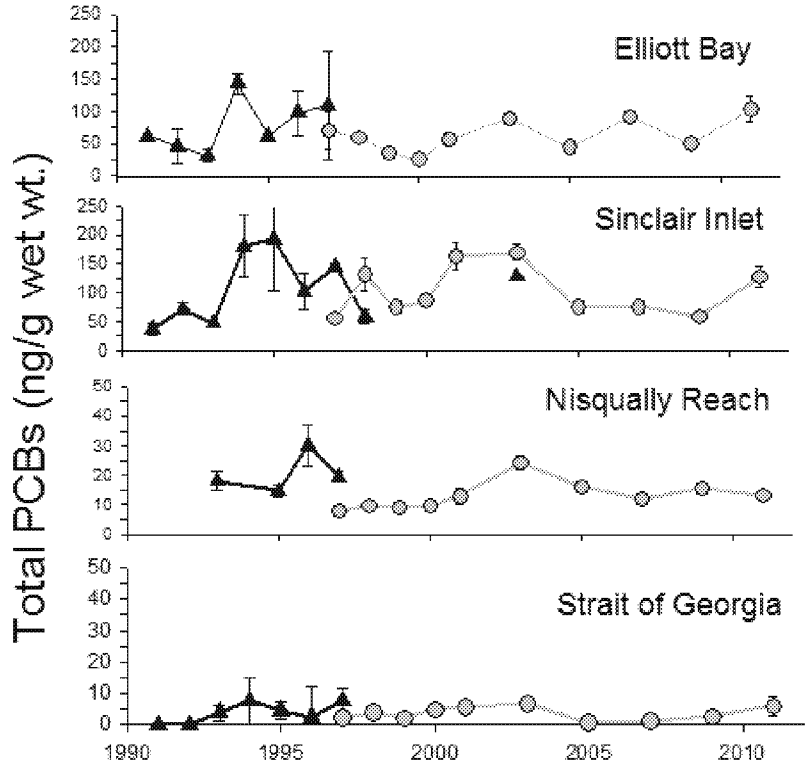

Figure 16: 20-year Time Series for PCBs in English Sole from Selected Urban and Non-urban Locations in Puget Sound (prepared by James West, WDFW; parts per billion; symbol shift indicates change in analytical method)

Long-term trend data are limited for Washington freshwater fish. PCB levels have declined in Spokane River fish since the early 1990s due to cleanup of hazardous waste sites, excavation and capping of contaminated river sediments, and reduced discharge from industrial and municipal treatment plants (Ecology 2011a, EPA, 2009).

The U.S. Geological Survey (USGS) analyzed changes in PCB residues in whole fish samples collected from 16 stations in the Columbia River Basin between 1970 – 1986, and in 1997 (Hinck et al., 2004). Not surprisingly, a number of sites had lower levels in 1997 than in the 70s or 80s. USGS observed, however, that criteria for the health of fish or wildlife were still exceeded and concluded that PCBs remain a cause for concern. Historical declines have also been documented for PCBs in Columbia River otter, mink, eagle, and osprey (EPA, 2009), all of which prey largely on fish. Here again, the comparison is primarily with samples collected in the 70s and 80s.

Current Levels and Spatial Patterns

Water

Due to the extremely low solubility of PCBs, there have been few attempts to measure concentrations in the water column. As part of the Puget Sound Toxics Loading Analysis

(PSTLA), Ecology analyzed PCBs at four sites in Puget Sound, three sites at the eastern end of the Strait of Juan de Fuca, and five major Puget Sound rivers in 2009-2010 (Ecology 2011d). Average concentrations in the Strait of Juan de Fuca (20 ppq) and Puget Sound (31 ppq) were lower than previously reported for the Strait of Georgia (42 ppq) by Canadian researchers (Dangerfield et al., 2007). The mean total PCB concentration in the five Puget Sound rivers was 16 ppq. The Puyallup and Stillaguamish Rivers tended to have higher concentrations (up to approximately 40 and 60 ppq, respectively) than the Skagit, Snohomish, or Nooksack (less than 20 ppq). Williston (2009) and Gries and Sloan (Ecology 2009a) report much higher concentrations in the Green/Duwamish River, up to 2,360 and 1,600 ppq total PCBs, respectively.

A surface water study conducted for PSTLA in 16 Puyallup and Snohomish county streams found higher PCB levels during storm-events than for baseflow conditions (Herrera, 2011). The median total PCB concentration was 348 ppq for storm-event samples compared to 227 ppq for baseflow samples. Washington's human health water quality criterion for PCBs is 170 ppq . Of the 70 samples analyzed, approximately 1/3 exceeded the criterion, primarily storm event samples. Except for a single sample, Washington's aquatic life criteria (ranging from 0.014 to 10.0 ppb) for PCBs were not exceeded

PSTLA estimated the total PCB load to Puget Sound and the U.S. portions of the Straits of Georgia and Juan de Fuca was 7 – 44 pounds per year (Norton et al., 2011). Surface water was identified as the major PCB pathway, accounting for 74-76% of the total load. Atmospheric deposition and publicly owned treatment works (POTWs) accounted for 18-20% and 4-8%, respectively, of the loading. PSTLA concluded there was insufficient data to estimate PCB loading from groundwater (Ecology 2011f).

Ecology and USGS have used passive sampling techniques (e.g., SPMDs) to concentrate and estimate PCB concentrations in other freshwater areas (McCarthy and Gale, 1999; Ecology 2012b, Ecology 2011a, Ecology 2005, Ecology 2004, Ecology 2010b; Ecology 2011m). Rivers, their tributaries, and lakes that have exceeded the human health criterion to the greatest extent:

- Columbia River: Wenatchee River, Willamette River (Oregon), Lake River
- Spokane River: (major pathway is stormwater)
- Yakima River: Granger Drain and Sulphur Creek Wasteway (stormwater also a major pathway)
- Walla Wall River: Garrison Creek
- Lake Washington

Water Quality Assessment list

There are 158 303(d) listings for PCBs in Washington's 2012 Water Quality Assessment. The federal Clean Water Act, adopted in 1972, requires that all states restore their waters to be

"fishable and swimmable." Washington's Water Quality Assessment lists the water quality status for water bodies in the state. The assessed waters are grouped into categories that describe the status of water quality. The 303(d) list comprises those waters that are in the polluted water category, for which beneficial uses– such as drinking, recreation, aquatic habitat, and industrial use – are impaired by pollution.

For the water body segments found to be impaired (category 5) Ecology conducts a total maximum daily load (TMDL) analysis and develops a cleanup plan for meeting water quality standards. Table 21 shows the PCB listings. There are 158 listings for PCBs in category 5. There are ten listings for PCBs in category 4a, which means a TMDL is completed and a plan is in place to meet water quality standards. Sinclair Inlet is in category 4b, which is similar to category 4a, but there is a pollution control plan instead of a TMDL. Fifty-six waterbody segments across the state are in category 2, meaning there is some evidence for elevated levels of PCBs, but there is not sufficient evidence to list it as impaired. Figure 17 is a state map of the category 5 and 4 listings along with the Washington DOH fish consumption advisories. DOH uses different guidance to develop fish consumption advisories and this is explained in more detail later in the section on Human Health. While the details of how a water body segment is considered impaired differs from how a fish consumption advisory is developed, there is a lot of overlap as seen in Figure 17.

Table 21: Water Quality Assessment for PCBs

Number of Waterbody Segments	Category	Description
158	5	Polluted waters that require a TMDL
11	4a and 4b	Polluted water that have a plan in place
56	2	Waters of concern

Figure 17: a. Category 4 and 5 303 (d) listings (blue dots). b. Waterbody-specific fish consumption advisories (blue lines, see section on Human Health). c. Overlap of water quality listings and fish consumption advisories.

Marine Sediments

PCBs have been extensively monitored in the marine sediments of Washington. Ecology has PCB data for 630 random sediment monitoring sites in Puget Sound and vicinity up through 2011, collected for PSEMP (e.g., Ecology 2013a).The highest levels are found in urban bays - Elliott Bay, Commencement Bay, Everett Harbor, and the Bainbridge Basin - with concentrations generally diminishing moving away from the shoreline (Figure 18). Particularly high PCB concentrations occur in the Duwamish and Hylebos Waterways in Seattle and Tacoma. Much lower levels are typically encountered in other marine areas.

Total PCBs in Washington marine sediments range from approximately 5 to 2,000 ppb (dry weight), with an overall median of approximately 15 ppb for the greater Puget Sound area. Ninety percent of PSEMP stations have a total PCB concentration below 40 ppb. Less than one percent exceed Washington State sediment quality standards (12 ppm, organic carbon

normalized). For perspective, the mean concentration reported for total PCBs in bottom sediments from the Duwamish Waterway Cleanup site is 1,100 ppb, with maximum concentrations as high as 220,000 ppb, dry weight (EPA 2013).

Freshwater Sediments

The PCB data on freshwater sediments are limited to studies focused on specific waterbodies or cleanup sites rather than large-scale monitoring programs as in Puget Sound. Spatial patterns for PCBs in Washington rivers and lakes are best illustrated with the more comprehensive fish tissue data, discussed below.

A regional freshwater sediment study by Ecology assessed the natural background for PCBs in northeast Washington (Ecology 2011h). Sediment samples were collected from fifteen lakes and one river thought to be minimally impacted by local human activity. Median and 90th percentile total PCB concentrations were 2.5 and 6.3 ppb, respectively. Atmospheric deposition is assumed to be the predominant PCB source to these waterbodies. By way of comparison, PCB levels in surface sediments of urban/industrial waterbodies such as Lake Washington and Lake Spokane approach 50 - 60 ppb (Ecology 2010a, Ecology 2011a).

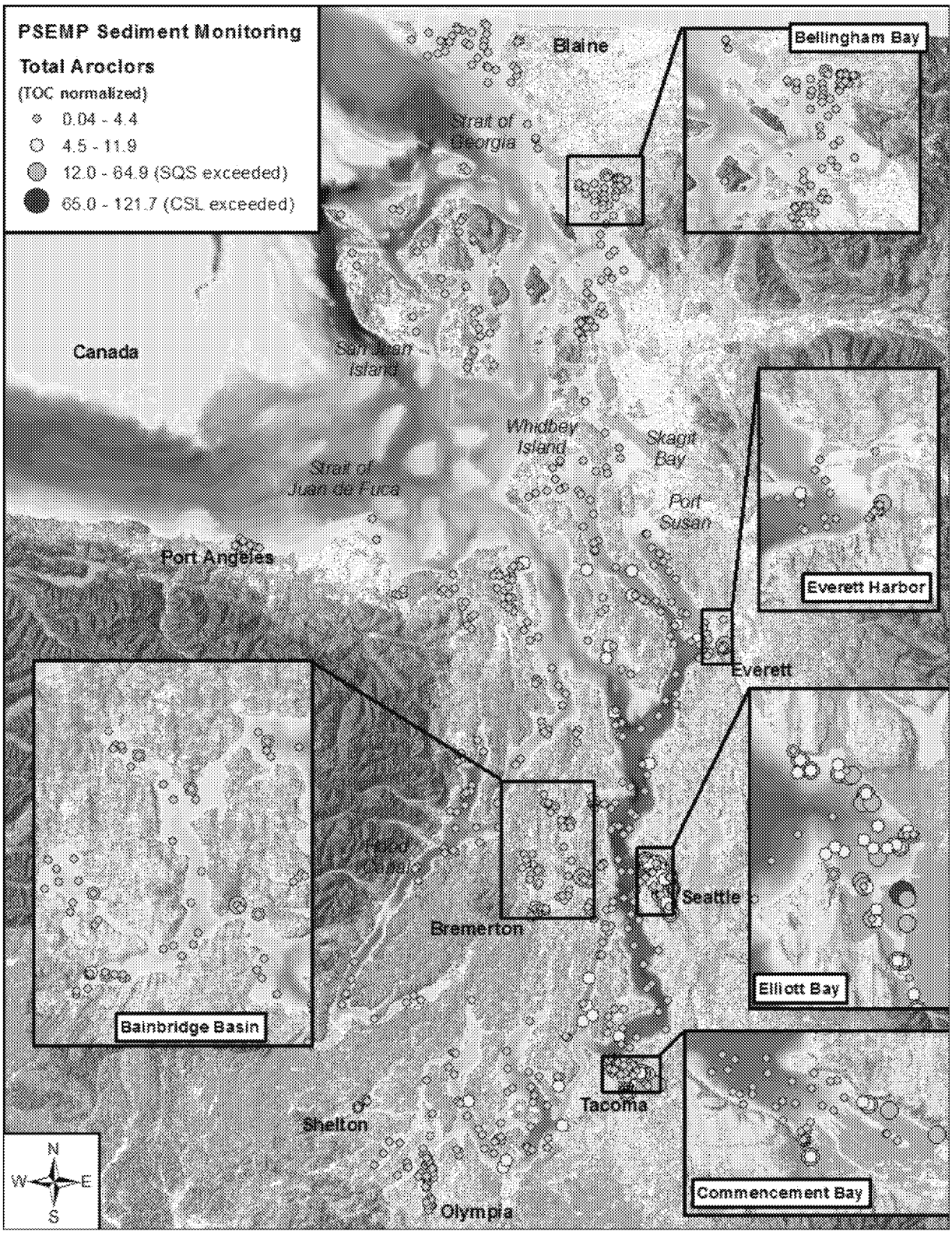

Figure 18: Distribution of PCBs in Marine Sediments from Puget Sound to Strait of Georgia (prepared by Sandra Weakland, Ecology Environmental Assessment Program; parts per billion, normalized to total organic carbon).

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Fish

WDFW has monitored PCB levels in Puget Sound marine fish since 1992. Figure 19 summarizes the total PCB concentrations measured in edible tissues of four important marine and anadromous species. The highest concentrations have been observed in herring (whole fish), followed by Chinook salmon, English sole, and coho salmon, in that order. Median and 90th percentile concentrations for these species are 159/234 ppb (herring), 44/95 ppb (Chinook), 23/135 ppb (sole), and 10/26 ppb (coho). The fish tissue equivalent of Washington's human health water quality criterion for PCBs is 5.3 ppb. All samples of herring and Chinook, and most (70 – 80%) of the English sole and coho have exceeded the criterion.

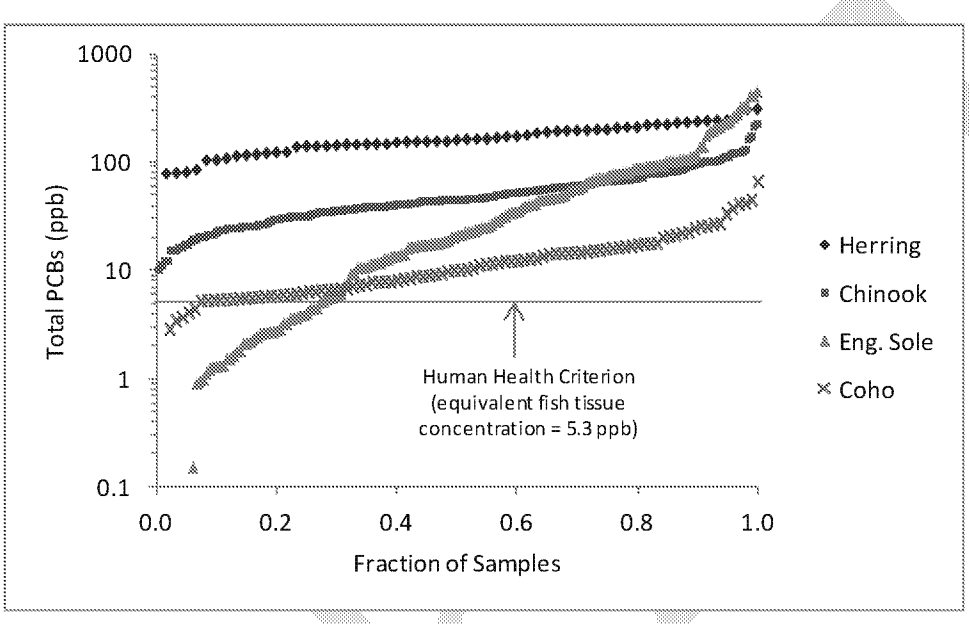

Figure 19: PCBs in Edible Tissues of Four Species of Puget Sound Fish (1992-2010 data provided by James West, WDFW; N =60 – 210)

Puget Sound herring are 3 to 9 times more contaminated with PCBs compared to Strait of Georgia herring (West et al., 2008). The high concentrations in this pelagic species suggest continued input of PCBs to the water column, rather than direct uptake from contaminated sediments (O'Neill et al., 2011). WDFW's herring studies show Puget Sound is a regional hot spot for PCBs in the food web on the Pacific coast (Figure 20). Within Puget Sound there is a gradient of decreasing PCB levels in plankton and several pelagic fish species moving away from urban areas (West et al., 2011a,b).

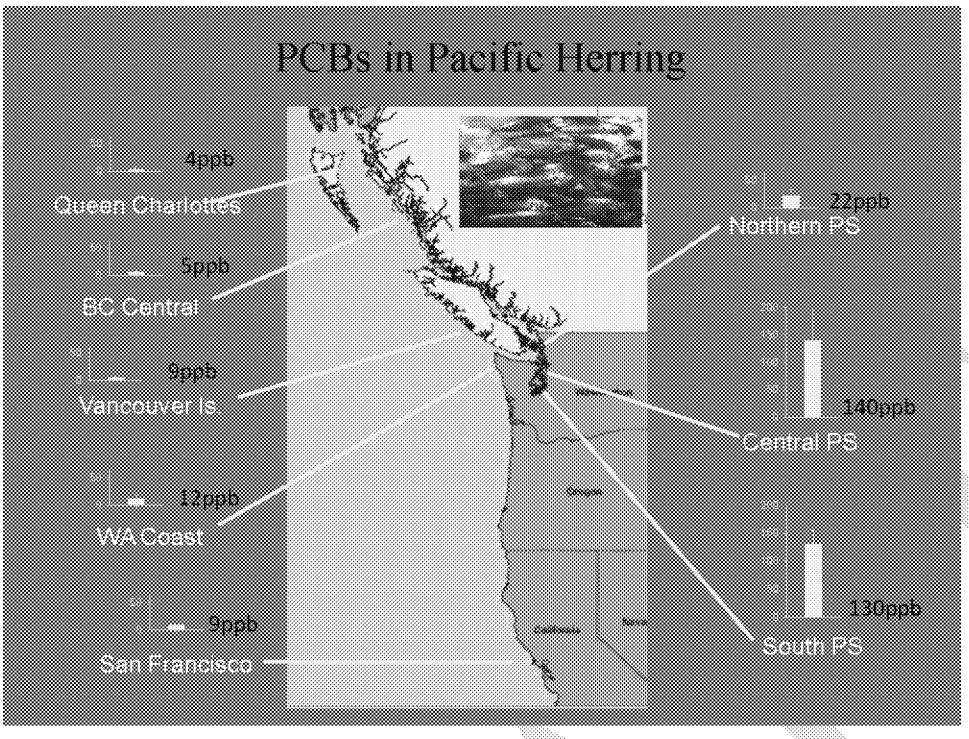

Figure 20: PCB Spatial Patterns in Herring: British Columbia, Washington, and California (prepared by James West, WDFW, and Sandie O'Neill, NOAA-NWFSC)

A high percentage of Chinook are resident in Puget Sound, with 29% of sub-yearlings and 45% of yearling out-migrants displaying resident behavior (O'Neill and West, 2009). Puget Sound Chinook are 3 to 5 times more contaminated than coastal Chinook (West, 2011). According to O'Neill et al. (2011), 23-100% of juvenile Chinook from Puget Sound urban bays and 19% of returning adult Chinook have PCB levels above effects thresholds. The lower levels in coho are more reflective of combined oceanic and Puget Sound conditions.

English sole show a strong north-south gradient in PCB concentrations, increasing from the Strait of Georgia into Puget Sound (Figure 21). Sole from urban bays, especially the Duwamish River estuary, have much higher PCB levels than fish from non-urban locations. The degree of contamination in Puget Sound sole is positively correlated with PCB levels in the sediments (West, 2011). Adverse effects on reproduction, growth, and immune response in English sole and other fish species have been attributed to the elevated levels of PCBs and other legacy contaminants in Puget Sound embayments (Collier, 2009).

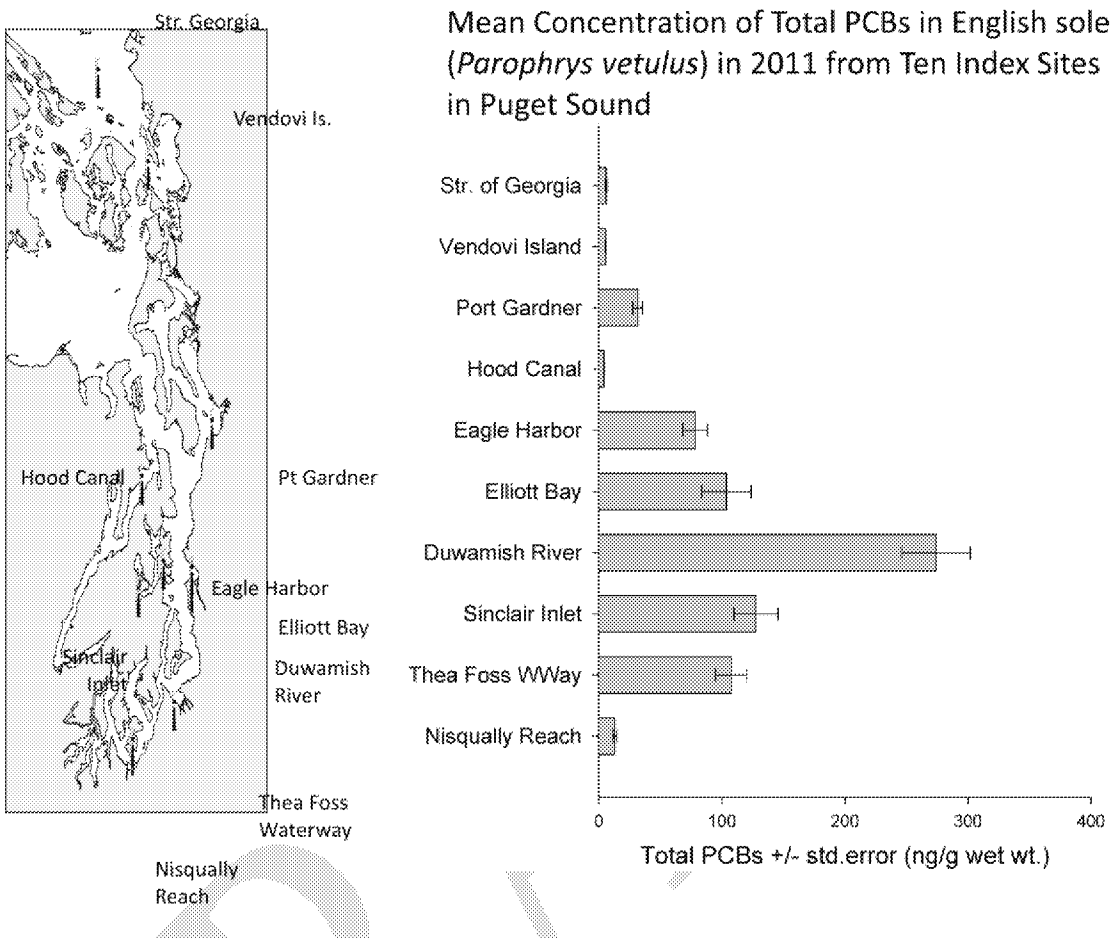

Figure 21: PCB Spatial Patterns in English Sole Muscle: Puget Sound and Vicinity (prepared by James West, WDFW; parts per billion).

A Pacific coast survey by the National Marine Fisheries Service showed outmigrating juvenile Chinook salmon typically have 2 to 5 times higher concentrations of PCBs and other contaminants compared to outmigrating coho (Ecology 2007). Of the 12 estuaries sampled, PCBs were highest in Chinook from the Duwamish River and Columbia River. The average PCB content in juvenile Chinook from these areas was near or above effects thresholds for growth and survival. For the Columbia River, the tidal freshwater portion of the estuary between Portland and Longview appears to be an important source of contamination. PCB levels were higher in fish that feed and rear in the lower river as opposed to those that migrate more rapidly through the estuary (Arkoosh et al., 2011; Johnson et al. 2013).

Figure 22 summarizes data obtained since 1997 on total PCBs in muscle tissue of resident freshwater fish collected throughout Washington, drawn from studies by EPA, Ecology, and others (CH2MHill, 2007; Delistraty, 2013; EPA National Lakes Fish Tissue Study, EPA, 2002; Johnson et al., 2004, 2007; Ecology Washington State Toxics Monitoring Program, e.g., Seiders et al., 2012). The statewide natural background for PCBs in edible fish tissue has been estimated

at 6.5 ppb (90th percentile; Johnson et al., 2010). Large areas of the state have relatively low PCB levels (<20 ppb) not greatly above background. However, elevated to high concentrations are also commonly encountered, especially in the Columbia River, some of its major tributaries, and the Seattle urban area. In approximate decreasing order, the following ten rivers and lakes are reported to have the highest total PCB concentrations in fish muscle samples (1,100 to 60 ppb, site average):

- Wenatchee River
- Lake Washington
- Middle Columbia River
- Green Lake (Seattle)
- Spokane River
- South Fork Palouse River
- Upper Columbia River
- Walla Walla River
- Lower Columbia River
- Snake River

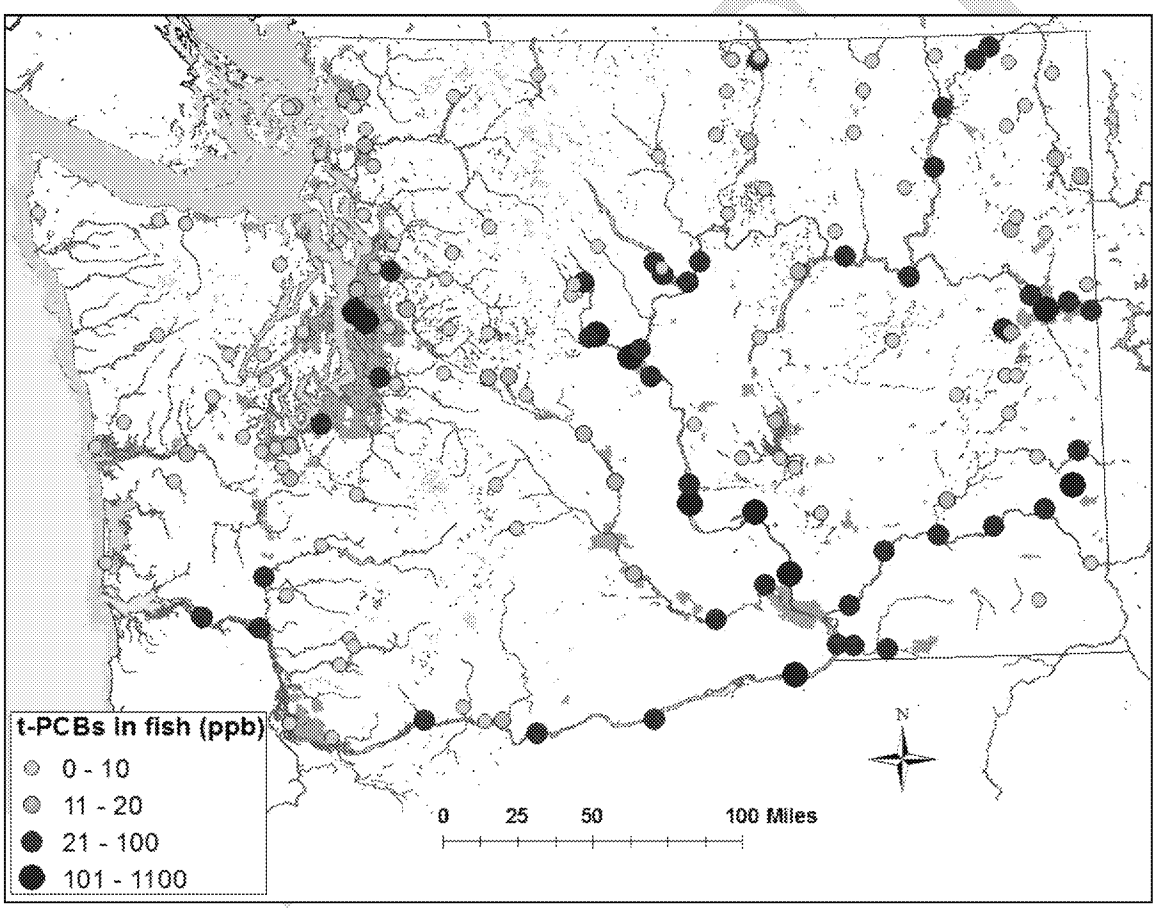

Figure 22: Average PCB Concentrations in Fish Muscle Samples from Washington Rivers and Lakes (prepared by Keith Seiders, Ecology Environmental Assessment Program; 1997-2010 data, N = 587).

Figure 26 in the section on Human Health shows statewide data on PCB levels in fish tissues. There is a line at 5.3 ppb, which is equivalent to the human health water quality criterion, and a

line at 23 ppm, which DOH uses as a screening level for advisories. About 60% of samples exceed the 5.3 ppb level calculated from the water quality criterion. The median concentration statewide for total PCBs in freshwater fish is approximately 10 ppb. Ninety percent of samples are less than 85 ppb.

High mountain lakes experience enhanced atmospheric deposition of PCBs due to colder temperatures and greater amounts of precipitation (Blais et al., 1998; Gillian and Wania, 2005). USGS analyzed PCBs in fish from 14 pristine Washington lakes over 3,000 ft. elevation (Moran et al., 2007). Although a relatively insensitive analytical method was used, total PCB concentrations of 17 – 20 ppb were found in approximately 20% of the tissue samples.

Mammals and Birds

Southern Resident killer whales are among the world's most PCB-contaminated marine mammals, which has been implicated in a range of negative health effects (Alva et al., 2012). It is estimated that Southern Residents have 4 to 7 times the daily PCB intake compared to Northern Residents (Cullon et al. 2009). Salmon, especially Chinook, comprise most of their diet and are thus the major source of contamination (Cullon et al., 2009). PCBs have been seen to cause reproductive impairment, immunotoxicity, skeletal abnormalities, endocrine disruption, and negative effects on population grown rate in marine mammals (Alva et al. 2012). While there are no established health effects thresholds for PCBs in killer whales, the levels in Puget Sound killer whales is above the health effects threshold for harbor seals that is based on immune system and endrocrine endpoints and predicted to remain high for decades (Hickey et al. 2007).

Total PCBs in blubber biopsy samples collected in 1993-1997 averaged 146 ppm (lipid weight) in Southern Resident males vs. 37 ppm in Northern Resident males (Ross et al., 2000). Southern resident males sampled in 2004/2006 averaged 62 ppm (Krahn et al., 2007). Females off-load PCBs during calving and lactation, resulting in lower concentrations than males, by about a factor of three in the 1993-1997 study. PCB levels rise quickly in nursing calves, then the levels fall as the PCBs are diluted with growth, with levels in males increasing with age and females increasing until the onset of reproduction (Hickey et al 2007).

A north-south gradient in increasing PCB levels has also been observed in harbor seals, which are non-migratory. Ross et al. (2004) reported average total PCB concentrations in adult seal blubber of 1.1 ppm in Queen Charlotte Strait, 2.5 ppm in the Strait of Georgia, and 18 ppm in Puget Sound. More recently, WDFW analyzed the blubber of 24 seal pups at four locations in Puget Sound (Noel et al., 2011). Total PCBs ranged from 1.0 to 9.4 ppm. Concentrations increased following the order Hood Canal < Whidbey Basin < South Sound < Main Basin (Figure 23). As with killer whales, indicators of adverse health impacts have been observed in harbor seals and linked to PCBs or other persistent organic pollutants (Cullon et al., 2012; Noel et al., 2011, Mos et al. 2010).

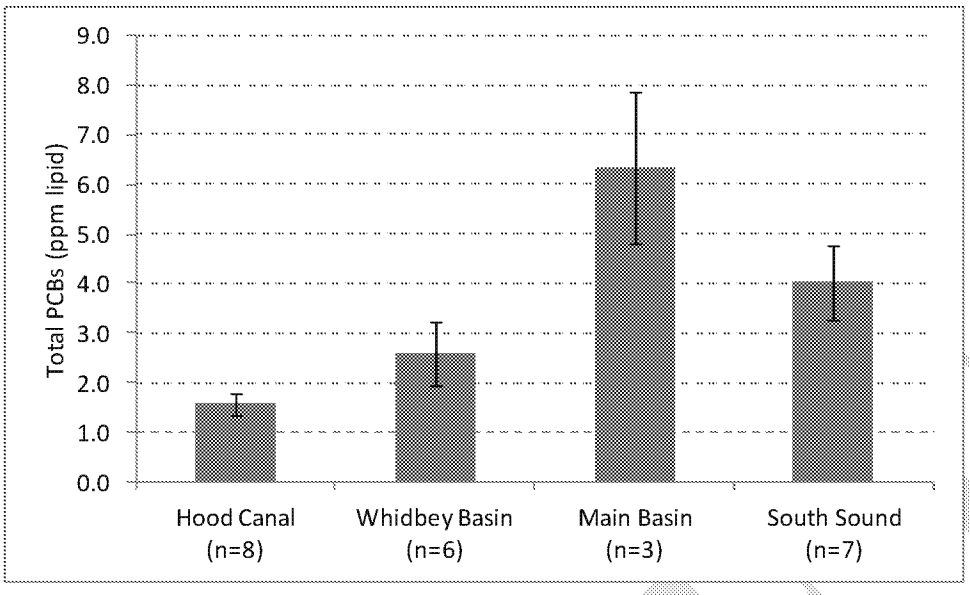

Figure 23: PCBs in Blubber of Puget Sound Seal Pups, 2009 (from Noel et al., 2011; mean and standard error)

USGS and USFWS have analyzed PCBs in lower Columbia River wildlife. Their most recent data (1990-2004) show average wet weight concentrations of 0.2 ppm in mink livers, 0.5 ppm in otter livers, 0.8 ppm in osprey eggs, and 5.4 ppm in eagle eggs (Henny et al., 1996; Grove et al., 2007; Henny et al., 2007; Buck et al., 2005).

Another USGS study reported mean total PCB concentrations of 0.8 ppm in osprey eggs collected from the lower Duwamish River in 2006-07, but noted these birds had been feeding largely on hatchery raised salmon smolts (Johnson et al., 2009). The significance of haematological and biochemical differences observed between eggs from the Lower Duwamish and a reference site (upper Willamette River) was unclear. The same study reported 2.6 ppm, 1.9 ppm, and 0.7 ppm total PCBs, respectively, in osprey eggs collected from Lake Washington, the Lower Duwamish River, and Snohomish River estuary in 2002-2003.

Cleanup Sites

There are 336 hazardous waste sites listed in Ecology's Integrated Site Information System (ISIS) as having confirmed or suspected PCBs. Many sites had multiple media with confirmed or suspected PCB contamination. Of the sites with confirmed or suspected PCBs in sediments, all but 15 also had soil with confirmed or suspected PCB contamination.

Table 22: PCB clean up sites

Medium	# of Sites	Confirmed	Suspected	Remediated	Below CUL
Soil	295	165	99	11	20
Groundwater	173	60	109	2	2
Sediment	62	47	11	1	3
Surface Water	89	19	64	6	0
Air	18	3	14	0	1

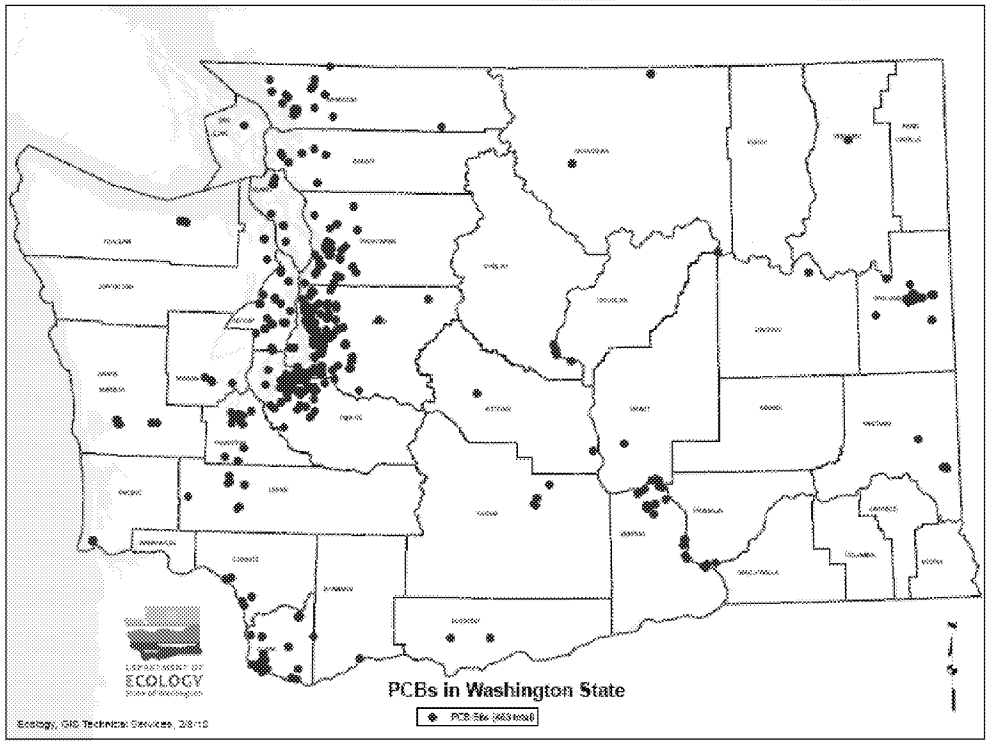

Figure 24: Figure of 483 PCB cleanup sites in Washington in 2010

Waste

Landfills

The material that remains after other parts are removed from automobiles at end of life for reuse or proper disposal is shredded and used as landfill cover. PCBs may be present in automobiles in hydraulic fluids, plastics, voltage regulators, electric motors, switches, small capacitors, and light ballasts, leading to PCBs in the shredder waste. This material is difficult to sample, due to its heterogeneity. However, PCB concentrations in untreated auto-shredder waste have been measured between 0.59 – 129 mg/kg and treated shredder waste contains 2.6 - 45.1 mg/kg (McKee et al.2006). McKee et al. further estimated that there is 270,000 tons of shredder waste from automobiles and appliances in California, leading to an estimate of to 30-6,970 kg of PCBs (Average = 3,500 kg) in untreated shredded waste and 140-2,440 kg of PCBs (Average = 1,300 kg) of treated shredder waste in the Bay Area.

Under federal TSCA, non-leaking small capacitors are allowed to be disposed of as solid waste. However, Washington State applies its own regulations to PCB electrical equipment containing 2 ppm PCBs or more and to materials contaminated to 2 ppm PCBs or more by electrical equipment. Unless the waste meets specific exclusions under the Washington State PCB rule (WPCB), these items must be properly disposed of and reported to Ecology as WPCB waste by the generator in annual data source reports. The code is for proper disposal and does not include more information on concentrations.

From 2009 – 2012, 10,577 MT of PCB-contaminated disposals were reported under WPCB (Table 23).

Table 23: PCB-contaminated disposals reported under WPCB

Year	WPCB (MT)
2009	2,322
2010	2,616
2011	1,310
2012	4,310

PCB-ballasts are considered moderate risk waste (MRW) when they are disposed of by households (household hazardous waste) and small businesses (small quantity generator waste). The weights reported include ballasts and shipping containers and we have not corrected for that due to the unknown weights of the shipping containers. Estimating that each ballast weighs 1.6 kg, and contains 44g of PCBs the estimated amount of PCBs ranges from 340 to 560 kg each year. Most of these PCB-ballasts go to a hazardous waste landfill outside of Washington State.

Table 24: PCB-ballasts collected as MRW (2010-2012)

Year	PCB-ballasts MRW (lbs)	PCBs (kg)
2010	32,871	410
2011	44,996	560
2012	26,885	340

Biosolids

Biosolids fall under the Clean Water Act (CWA) and the 503 rule (40 CFR 503). There are no requirements to monitor PCBs in biosolids, nor a regulated level of PCBs in biosolids. EPA(1995) made a "policy decision to delete all organic pollutants from land application and surface disposal sections of the final Part 503 rule because these pollutants met one of the following criteria: (1) the pollutant has been banned or restricted for use in the United States or it is no longer manufactured for use in the United States; (2) the pollutant is not present in biosolids at significant frequencies of detection based on data gathered in the NSSS [the National Sewage Sludge Survey], or (3) the limit for a pollutant from the biosolids exposure assessment is not expected to be exceeded in biosolids that are used or disposed based on data from the NSSS." EPA continues to investigate pollutants in sewage sludge and uses risk analysis to ascertain which pollutants require monitoring and regulatory levels.

While neither federal nor state regulations require testing of biosolids for PCBs, some jurisdictions such as King County, have tested for PCBs in biosolids (King County 2007). In 2006 Aroclor 1248, 1254, and 1260 were detected and other Aroclors were not detected at the West Point Treatment Plant. Only Aroclor 1254 was detected at the South Treatment Plant. Historically PCB Aroclors have been detected in King County biosolids at the ppb level. We do not have enough information to estimate the amount of PCBs in biosolids in Washington.

PCBs have also been measured in a few samples of Canada Goose guano in the Lower Duwamish area. In four composite samples the total Aroclor PCBs ranged from 28-103 ppb with an average concentration of 58 ppb. This is generally indicative of the ubiquitous nature of PCBs in Washington. This is not enough information to estimate the amount of PCBs in goose guano in Washington.

Environmentally Significant PCBs

As a result of partitioning, transformation, and bioaccumulation, PCB mixtures in the environment do not resemble the commercial products. About half of the 209 possible congeners account for most of the environmental contamination. Based on toxicity, prevalence, and relative abundance, the number of environmentally significant congeners is less than 40. Twenty-five of these account for 50-75% of the total PCBs in biological tissues (McFarland et al., 1989).

In Washington and elsewhere, PCBs with three to six chlorines (tetra- through heptachlorobiphenyls) are the dominant compounds in environmental samples. Less chlorinated compounds are more volatile and more readily metabolized and eliminated from organisms.

Highly chlorinated compounds are relatively less abundant, more tightly bound to sediment particles, and taken up poorly by fish and other aquatic animals.

Twelve PCBs have a co-planar configuration that imparts dioxin-like toxicity (Tables 20 and 25). These compounds are frequently detected in Washington's environment. PCB-118 is the co-planar most often encountered in the highest concentrations (Cleverly et al., 1996; Noel et al., 2011). The most toxic co-planar, PCB-126, is typically present at the lowest concentrations.

Although their toxicity is low relative to dioxin - a tenth or less – these PCBs can impart a significant fraction of the total dioxin toxicity equivalents (TEQ), particularly in higher animals. Co-planar PCBs accounted for up to 89% of the total TEQ in harbor seal pups collected from Puget Sound in 2009 (Noel et al., 2011). PCB-118, -105, and -156, in that order, were the major contributors to the TEQ. Cullon et al. (2009) reports that PCBs explained the majority of the TEQ in adult salmon from British Columbia and Puget Sound waters. In contrast, the PCB TEQ in Washington freshwater fish is typically much lower than the dioxin TEQ, by an order of magnitude or more in most cases (CH2MHill, 2007; DOE, 2010; Johnson et al., 2010).

PCB-11, a non-legacy PCB, has been identified in Columbia River water and clams (Johnson and Norton, 2005; McCarthy, 2007). In some samples, PCB-11 was either the most or second-most abundant congener detected. PCB-11 is neither associated with historical commercial PCB products nor a breakdown product of the commercial mixtures. The source has been traced to pigments currently used in paint (Hu and Hornbuckle, 2010). Reports of PCB-11 in environmental samples have become widespread in North America (Litton 2006; Grossman, 2013). PCB-11 is considered a significant source of contamination to air, soil, and water (Hornbuckle and Robertson, 2010).

Model Predictions

Ecology has modeled the long-term fate and bioaccumulation of PCBs in Puget Sound (Ecology 2009b). Pertinent findings from Ecology's box model include the following:

- Approximately 97% of the total mass of PCBs in the aquatic ecosystem of Puget Sound is in the active sediment layer (top 10 cm), about <1% is in the water column, and about <3% is in the biota.
- Decreases in PCBs in sediment and biota are possible by the year 2020 in the urban bays due to burial and transport of sediments.
- Increases in PCBs in sediment and biota are possible by the year 2020 in the larger basins.
- Considering the wide range of uncertainty in external loading, it is possible the mass of PCBs in the aquatic ecosystem of Puget Sound may either increase or decrease over time at the current loading levels.

Ecology is currently re-evaluating this model using more recent data. The revised analysis will be completed in spring 2014.

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A delayed response to environmental declines in PCB levels is predicted for long-lived species like killer whales (~50-year lifespan). According to an individual-based model, Southern Resident killer whales may not fall below PCB effects thresholds for several more generations (Mongillo et al., 2012; Hickie et al., 2007).

Food web models for Lake Washington and the Spokane River conclude that PCB residues in fish are driven mainly by levels in the sediments (Era-Miller et al., 2010; Serdar et al., 2011). Thus, recovery in these waterbodies may respond slowly to reductions in external PCB loading.

Results of a mass balance model for the Willamette River basin in Oregon demonstrated that the PCB levels observed in fish could be obtainable entirely from the atmosphere due to global legacy sources (Hope, 2008). In this analysis, PCB sources within the Willamette basin were assumed to be insignificant. Portland was discounted because it occupies a short segment of the lower river isolated by Willamette Falls. Assumptions aside, the model illustrates the importance of focusing chemical action plans on significant PCB sources that are amenable to control.

Local Hazard Assessments

Spokane River

The Spokane River has elevated levels of PCBs in Washington and Ecology published An Ecological Hazard Assessment for PCBs in the Spokane River (2001) for aquatic life and fish-eating wildlife. Hazard quotients (HQs) were calculated for different endpoints and receptors in six different parts of the river. The HQs are ratios of the level of PCBs in the environment and the level at which no adverse effects is expected. If the HQ is greater than 1, then adverse health effects are possible, but do not necessarily occur.

The primary ecological hazards identified were:

1. Possible adverse effects on the sustainability of salmonid populations and fish-eating mammals, primarily in the reach between Trentwood and Nine-Mile Dam.

PCB levels in salmonid fish tissue were high compared to the National Marine Fisheries Service (NMFS) effects threshold for sublethal effects (HQs 2.2-4.1).

The levels of PCBs in water were high compared to the Great Lakes criterion for reproductive effects on fish-eating mammals (HQs 4.5-17). Also the PCB levels in fish tissue were high when compared to the British Columbia guideline for reproduction in fish eating wildlife (HQs 2-6) and compared to the lowest observable effects levels (LOEL) for mink and otter reproduction (HQs 1.5-2.4).

2. Possible adverse effects on benthic invertebrates in the Trentwood to Monroe Street Dam reach in areas where PCBs have been concentrated in fine-grained sediments, such as behind Upriver Dam. The levels of PCBs in sediment were high compared to the threshold effect for abundance and diversity of benthic invertebrates (HQs 2.5-9.8)

Puget Sound

As part of the larger, multi-year, multi-agency, project to study toxic chemicals in Puget Sound, the Assessment of Selected Toxic Chemicals in the Puget Sound Basin, 2007-2011 (Ecology 2011) included a hazard evaluation to estimate the relative hazard posed by the 17 chemicals of concern assessed in the Puget Sound studies. This was not a risk assessment, but part of the effort to prioritize efforts on pollutants in Puget Sound. The hazard evaluation was for the entire sound, not for hot spots where there are higher levels of contamination, such as in cleanup sites. PCBs were found to be the highest level of concern for a range of media and receptors in both the freshwater and marine aquatic environments.

PCBs were found to be at the highest level of concern (Priority 1) for the five categories assessed. The category and the reason PCBs were placed in Priority one is given below for each.

- Aquatic life through surface water exposure. The 90th percentile of observed concentrations of Aroclors was above the chronic Water Quality Standard (WQS) for aquatic species in freshwater.
- Benthic organisms through sediment exposure. The 90th percentile of the observed concentrations exceeds the Sediment Quality Standard for Aroclors for freshwater (FP-SQS) and offshore marine sediment (SQS).
- Tissue Residence Effects. The 90th percentile of observed concentrations was above the 10th percentile of the effects concentration for non-decapod invertebrates for both Aroclors and total congeners.
- Wildlife through seafood consumption. Using Great Blue Heron, Osprey, River Otter, and Harbor Seal as representative species, the daily dose was more than the lowest effect dose/10.
- Human health through seafood consumption. The 90th percentile of observed concentrations was above National Toxics Rule (NTR) water quality criteria for freshwater, nearshore marine, and offshore marine for both Aroclors and congeners for bivalves, fish and invertebrates. Tissue criteria were back calculated from the NTR based water quality criteria.

Environmental data from January 2000 to July 2010 were collected from a variety of sources, and the largest source of data was Ecology's Environmental Information Management (EIM) system. Information on effects levels were found in the scientific literature and regulatory benchmarks. Comparisons to effects levels, criteria, and guidelines were done separately for both PCB Aroclor and congener data. Box Plots showing these comparisons can be found in the Assessment report Appendices D3-D7 (https://fortress.wa.gov/ecy/publications/summarypages/1103055.html).

Human Health Effects of PCBs

Introduction

There is a very large body of toxicological and epidemiological research on the health effects of PCBs. Research conducted in experimental animals has shown that PCBs can cause a wide variety of adverse health effects including, immune suppression, adverse reproductive effects, abnormal motor and cognitive development, injury to the liver and other internal organs, changes in the endocrine system, and cancer. Epidemiological studies have found evidence of similar adverse effects on human development and behavior, reproduction, immune function, and cancer (ATSDR 2000). The International Agency for Research on Cancer (IARC) recently changed their classification of PCBs and dioxin-like PCBs from "probable human carcinogens" to "human carcinogens" to recognize that there is now sufficient evidence in humans and animals. (Lauby-Secretan et al., 2013)

The primary historic uses of PCBs were banned in 1979 but existing electrical equipment and other closed systems containing PCBs were permitted to remain in use (EPA 40 CFR part 761). Caulk, joint sealant, paint and other building materials sold before 1979 may have contained PCBs and could still be in place. PCBs have continued to slowly escape from these historic sources with rapid releases during leaks, fires and building demolition.

Historically, PCB oils and equipment containing those oils have been disposed in ways that allowed PCB release into the environment. A number of waste sites in Washington have been identified as contaminated with PCBs. Many have been cleaned up but more clean-up remains. Because many PCBs are persistent and bioaccumulative, these legacy sources of PCBs continue to cycle through air, water, soil, sediments, and biota. Although general environmental levels have dropped dramatically since 1979, human exposure to legacy PCBs in fish, other foods, and air will continue into the future.

In addition, PCBs are inadvertently formed during current production of certain pigments and ink (Hu and Hornbuckle 2010). These PCBs have been detected in colored papers, cardboard, plastics, and textiles and may be released to the environment during manufacturing, use, disposal or recycling of consumer products (Litten et al 2002; Rodenburg 2010). PCB 11 has emerged as a useful indicator of these new sources of exposure since commercial PCBs mixtures did not contain more than trace amounts of PCB 11 (Frame et al. 1996, Schultz et al. 1989, Grossman 2013).

There are 209 possible configurations of chlorine substitutions of the biphenyl molecule. Each possible configuration (called a congener) is assigned a number and most can now be quantified analytically. Because congeners vary in their toxicity and their resistance to metabolism, risk

assessment of PCB mixtures is complex. One of the earliest discoveries in the search for common mechanisms of toxicity was that certain congeners have dioxin-like ability to bind to the aryl hydrocarbon receptor. Dioxin-like PCBs are planar or nearly planar in structure (Van den Berg et al. 1998). Their interaction with the Ah receptor is dose-dependent, saturable and induces hepatic enzymes, including aryl hydrogen hydroxylase (also called cytochrome p450 CYP1A1) and 7-ethoxyresorfin *O*-deethylase (CYP4501A2) (Safe 1992, Seegal 1996). These enzymes metabolize (or breakdown) a number of environmental chemicals but also act on important endogenous chemicals such as hormones, retinoids, and neurotransmitters (ATSDR 2000).

Several toxic responses have been well correlated with the Ah-receptor binding affinity, including body weight reduction, hepatotoxicity and thymic atropy (Seegal 1996). Laboratory animals exposed solely to coplanar PCBs have shown reproductive problems, increases in brain levels of biogenic amines including dopamine, alterations in fetal and neonatal plasma thyroid hormone levels, and neurobehavioral effects (Brouwer et al. 1995). Available evidence in lab animals suggests that the maturation of the immune system is especially vulnerable to adverse effects of dioxin-like compounds (Holladay and Smialowicz 2000). Toxic equivalency factors (TEF) have been developed to facilitate risk assessment of mixtures of dioxin-like chemicals and currently includes 12 PCB congeners (Van den Berg et al. 1998, 2005).

EPA and ATSTR have established health recommendations concerning oral intake and inhalation of PCBs. These screening levels help public health agencies and communities identify exposures of concern. The three primary pathways of current PCB exposure for the U.S. general public are diet, indoor air, and ambient air. Ingestion of PCB residues in house dust could be a significant contributor to exposures in toddlers (ATSDR 2000, Harrad et al 2009). Although background exposures in the US population appear to have dropped below levels of concern, special populations at higher risk for exposure exist and require attention. These include people who work around PCB contaminated equipment or materials, who consume fish and seafood from contaminated waters, or who live or work in a building with PCBs in building materials or fluorescent light ballasts.

Summary of Health Effects of PCBs

There have been two episodes of mass human poisoning by PCB contaminated rice oil. One occurred in Japan in 1968 and the other in Taiwan in 1978-79. Affected people in Japan were diagnosed with "Yusho" which means "the oil disease" and in Taiwan with "Yu-Cheng," the term for "oil disease" in Taiwanese. About 1700 adults were acutely affected in the Japanese incident. Exposure of adults resulted in increased skin pigmentation, severe acneform eruptions, swelling of the meibomian gland with eye discharge, thickening of the nail bed, and numbness in extremities, and respiratory disease (Urabe and Asahi 1985, Ikeda 1996, Nakanishi et al. 1985). Affected women who were pregnant at the time gave birth to children with physical

abnormalities (dental disorders, hyperpigmentation of skin) and severe neurodevelopmental problems (Seegal 1996). Exposure monitoring for PCBs in blood of Yusho patients did not begin until five years after the onset of disease.

About 2000 persons were initially affected with illness in the Taiwan incident. Symptoms included hyperpigmentation, acneform eruptions, swelling of eyelids and increased discharge from the eyes, as well as systemic complaints (Lu and Wu 1985). Women who were pregnant at the time of exposure gave birth to children who showed hyperpigmentation, nail deformities, conjunctival discharge and swelling. Eight of the 39 infants born with hyperpigmentation during the 4 years following the incident died (Hsu et al 1985). A cohort of most of the Taiwanese children (n =118) born to affected mothers up to six years past the incident has been followed and tested annually for cognitive deficits. A comparison population with the same number of children was matched on maternal age, child's birthdate, gender, and neighorhood of residence. Blood PCB levels of Yu Cheng patients were measured early in the disease outbreak and were high (44.4% of 613 patients sampled had blood levels of PCBs between 51-100 ppb. The highest value reported was 1156 ppb (Hsu et al., 1985). Yu-Cheng offspring have been shown to have persistent cognitive deficits, lower IQ, and higher rates of problem behaviors compared to neighborhood controls (Lai et al 2002).

Immune effects were also reported in both groups of poisoned people. An increase in respiratory and skin infections was observed as well as significant changes in immune parameters such as immunoglobulins and T cells (Lu and Wu, 1985). Studies also detected depressed responses to tuberculin tests (Lu and WA 1985, Nakanishi et al, 1985). Infants born to mothers who had Yu-Cheng disease had more episodes of bronchitis or pneumonia during their first 6 months of life and had higher frequencies of ear infection and respiratory tract infection in a 6 year follow-up (Yu et al 1998).

There is debate about the degree to which these two mass poisonings are relevant to current assessments of PCB exposure (Schantz 1996, Seegal 1996). The levels of PCB intake were very high compared to modern sources and PCBs in both incidents were repeatedly heated to high temperatures in a heat exchanger before contamination of rice oil occurred. The high temperatures changed the chemical composition of the oil creating high concentrations of polychlorinated dibenzofurans (PCDF) and other toxic compounds. Many of the developmental and physical effects seen in these populations, however, are also observed in monkeys dosed with pure PCB mixtures.

Developmental abnormalities have also been observed in occupationally exposed populations. A seven-year follow-up study of capacitor manufacturing workers in Japan and their children evaluated effects on children born to mothers who had PCB blood and breast-milk levels that were 10-100 times the normal background and markedly higher than the blood of Yusho patients. Forty children were examined once a year for five years and none were diagnosed with PCB poisoning. Some of the children were found to have decay of nails, gingival pigmentation,

mottled enamel, and dental caries which were typical symptoms in Yusho but were less serious in this study population (Hara 1985).

Endpoints of concern for environmental and occupational exposure to PCBs

Cancer

There is clear evidence that commercial PCB mixtures cause cancer in animals in a dose-dependent manner (EPA 1996, ATSDR 2000). Cancers observed primarily involve thyroid and liver tissue. In a series of recent investigations, the NTP demonstrated that dioxin-like congeners, PCB 118 and PCB 126, were able to induce lung, liver, bile duct, oral, and uterine cancers in rodents (NTP 2006). Studies of workers exposed to commercial PCB mixtures found increases in liver and bile-duct cancers and malignant melanoma across multiple human studies (NTP 2011, Lauby-Secretan et al 2013).

PCBs are generally thought to induce cancer through indirect mechanisms (ATSDR 2000, WHO 2003). PCB mixtures and specific congeners can act as tumor promoters (EPA 1996). Tumor promotional activity has been observed by congeners that are aryl hydrocarbon agonists (dioxin-like congeners), induce cytochrome P450 1A and 2B isozymes, and induce P450 CYP2 and CYP3 families of enzymes and have a phenobarbital pattern of enzyme induction (ortho-substituted congeners). Oxidative stress and disruption of intercellular communication have also been proposed as mechanisms. (EPA 1996, WHO 2003).

EPA and NTP consider PCBs to be probable human carcinogens and recently IARC strengthened its classification of PCBs to "human carcinogens" based on new evidence of melanoma in epidemiological studies (Lauby-Secretan et al. 2013). EPA concluded that the types of PCBs likely to be bioaccumulated in fish and bound to sediments are likely to be the most carcinogenic PCB mixtures. (EPA 1996)

In addition, there is clear evidence that PCBs have significant non-cancer toxic effects including effects on the immune system, the reproductive system, the nervous system and the endocrine system. These are outlined briefly below.

Immune Effects

Numerous immune effects have been measured in laboratory animals exposed to PCBs (reviewed in ATSDR 2000). Changes in the immune system were selected by both ATSDR and EPA as the most sensitive non-cancer endpoint for chronic exposure to PCBs. In the critical study chosen by these agencies (Tryphonas et al. 1989, 1991a, 1991b), PCB-treated rhesus monkeys had a dose-related reduction in antibody response to an injected antigen (sheep RBC). The diminished production of immunoglobulins IgM and IgG, in response to antigen was statistically-significant at two time points during the study (27 months and 55 months) at the

lowest dose of Aroclor 1254 tested: 5 ug/kg/d. No differences in baseline serum concentrations of IgG, IgM or IgA were evident. Both EPA's Reference dose for chronic exposure and ATSDR's minimal risk level were derived from findings of this study at the 5 ug/kg/d dose level (EPA 1994, ATSDR 2000). Shifts in subsets of lymphocytes were detected at 27 months but not after 55 months of dosing and only at the highest dose tested (80 ug/kg/d). Specifically, there was an increase in T-cytotoxic/suppressor (T_S) lymphocytes and a reduction in T-helper/inducer (T_H) lymphocytes. Changes in the T_H / T_S ratio are of uncertain clinical significance but a decrease in the monkeys's ability to respond to an antigenic challenge may lead to diminished resistance to microbial infection. Body burdens after 25 months of dosing at 5 ug/kg/d were reported to be 10.3 ppb in blood (8.4 ppm in blood when expressed on a lipid basis) and 2.2 ppm in adipose tissue (7.5 ppm in adipose when expressed on a lipid basis) (Arnold et al 1993a, 1993b).

The experiment above continued into a breeding phase to measure reproductive and developmental outcomes in the rhesus monkeys. Female monkeys treated for 37 months with Aroclor 1254 were bred to unexposed males. Among other things, offspring were tested for immunological function. A reduction in titres to SRBC (IgM) were statistically significant for the 5 ug/kg/d dose level at multiple post-natal time points (Arnold et al. 1999).

In this study of rhesus monkeys the immune system was not the only endpoint of concern. Statistically significant but clinically mild developmental abnormalities were observed in offspring at the 5 ug/kg/d dose level including nail and nail bed changes, and inflammation and/or enlargement of the tarsal glands. There were also adverse reproductive effects that were elevated but did not reach statistical significance at the 5 ug dose (Arnold et al. 1999).

A number of epidemiological studies have reported immune effects associated with human environmental exposures to PCBs. Inuit children with high exposure to PCBs and other organochlorines, were reported to have higher incidence of ear infection and lower but not upper respiratory tract infection during the first 5 years of life (Dallaire et al 2006). Early life exposures to PCBs have also been associated with reduced response to childhood vaccinations in European children (Weisglas-Kuperus et al. 2000, Heilman et al. 2006) and reduced size of the thymus (Park et al. 2008).

Neurological and Neurodevelopmental Effects

Extensive animal research on neurologic impacts of PCB shows adverse effects in adults and the young with fetal and early postnatal periods being the most sensitive in producing adverse effects in rodents and monkeys (Brouwer et al. 1995). Hyperactivity and learning and memory impairments are very sensitive to developmental PCB exposure in non-human primates (Bowman et al. 1978, Schantz et al. 1991). ATSDR based their health advice for oral PCB exposure over intermediate durations on learning and memory impairments observed after postnatal exposure to a PCB in male rhesus monkeys (ATSDR 2000). In this study, Rice et al.

created a congener mixture that represented 80% of the congeners present in breast milk in Canadian women and administered it for 20 weeks postnatally at a dose estimated to be equivalent to nursing from a mother with 50 ppb PCB in breast milk (0.0075 mg/kg/d). Behavioral tests were conducted 3-5 years later. Treated monkeys were slower to learn new responses, adapt to new response patterns, and inhibit a response that was previously rewarded (Rice 1999). This study suggests that the congeners that bioaccumulate in people, are more potent than commercial mixtures.

A number of studies have reported developmental effects in children although PCB levels in cord blood at birth or in the mothers were significantly higher than current body burdens in most populations. Some studies, such as the Michigan Maternal/Infant Cohort and the Oswego Newborn and Infant Development Project, compared pregnant women who consumed Great Lakes fish to mothers who did not. Other studies, such as the North Carolina Breast Milk and Formula Project and the Dutch PCB/Dioxin Study, focused on mothers in the general population. These studies reported a range of subtle neurobehavioral effects such as abnormal newborn reflexes, cognitive and memory deficits including decrease IQ and changes in physical activity that were associated primarily with *in utero* not lactational PCB exposure (Jacobson and Jacobson 1996, Stewart et al 2008, Brouwer et al 1995). Although some studies have measured effects of lactational exposure to PCBs via breast milk, breast feeding appears to have a net positive effect in people with regard to mental and physical development (Anderson 1999, Boersma and Lanting 2000; Pan et al. 2009). Fish consumers had higher proportions of PCB congeners with 7-9 chlorines and in one analysis these congeners were shown to be more closely associated with the neurobehavioral effects observed (Stewart et al 1999). In another study, maternal body burden of dioxin-like mono-ortho substituted congeners (PCBS 118 and 156) were most strongly associated with neurobehavioral outcomes in children (Park et al. 2010).

Reproductive Effects

Reproductive effects of PCBs have been demonstrated in a variety of animal species including non-human primates (ATSDR 2000). Oral PCB exposures reduced birth weight, conception rates and live birth rates of monkeys exposed during preconception and gestation (Arnold et al 1995). Similar results have been observed in rodents. Developmental exposures in rodents resulted in lasting changes in reproductive tissue which were measurable at puberty and into adulthood (WHO 2003).

Investigations of reproductive effects have also been carried out in human populations exposed to PCBs. Longer time to pregnancy for couples trying to get pregnant has been reported to correlate with higher levels of certain PCB congeners (Axmon et al 2005, Buck Louis et al 2013). Obvious growth retardation was observed in offspring following the Yusho and Yu-Cheng incidents. Children born to women who worked with PCBs in factories showed decreased birth weight and a significant decrease in gestational age with increasing exposures to PCBs (Taylor et al 1989, Hara 1985). Studies in fishing populations believed to have high exposures to

PCBs also suggest similar decreases in either birth weight or gestational age or both (Fein et al 1984, Rylander et al 1995). Govarts et al. 2012 reported that birth weight decreased with increasing cord serum concentration of PCB-153 after adjustment for potential confounders in 12 of 15 study populations in Europe. Several studies have observed persistent deficits in physical growth into childhood following prenatal exposure to PCBs, particularly in girls (Jacobson and Jacobson 1997, Lamb et al 2006, Blanck et al 2002).

Other investigations did not detect lower weight or shorter gestation times in other populations, including fish consumers (Rogan et al 1986; Patandin 1999; Dar et al 1992, Buck et al 2003, Cupul-Uicab et al 2013).

Endocrine Effects

There has been significant discussion and research on the effects of PCBs on the endocrine (or hormone) system. A number of PCB congeners and their metabolites display weak estrogenic, antiestrogenic effects, or antiestrongenic effects (Hamers et al 2011, Brouwer et al 1999, Birnbaum 1994). Certain PCBs and their metabolites appear able to directly interfere with estrogen or androgen receptors show direct binding affinity for the estrogen receptor while others may act indirectly by inducing enzymes that then change estrogen metabolism (Brower et al 1999, Kester et al 2000, Hamers 2011).

The strongest evidence is for disruption of thyroid hormone levels. Hydroxylated PCB metabolites are structurally similar to thyroxine (T4) and may interfere with hormone receptor binding directly. They have been shown to competitively displace binding of thyroid hormone (T_4) to transthyretin in rodents and to disrupt the normal delivery of thyroid hormone from maternal plasma to the rodent fetus *in vivo* (Porterfield 2000, Brower et al., 1999). In addition, PCBs and their metabolites may act indirectly by interfering with thyroid hormone metabolism. For example, activation of the Ah receptor by dioxin-like PCBs, induces production of the enzyme uridine diphosphoglucuronyl transferase that metabolizes T4 and may accelerate T4 clearance from the liver (Porterfield 2000, Koopman-Esseboom *et al.*1994). Thyroid hormones are essential for regulating metabolism and normal growth and brain development. They also promote normal cardiovascular, reproductive and nervous system functioning.

Dioxin-like PCBs have been associated with changes in thyroid hormone levels in infants (Koopman-Esseboom et al 1994; Nagayama et al 1998; Pluim et al 1992). A more recent study by Wilhelm et al 2008, looked for but did not find any decrease in thyroid hormones related to dioxin-like PCBs or total TEQ at current exposure levels in Germany. Chevrier et al 2007 reported that blood concentration of thyroid stimulating hormone in newborns was associated with non-dioxin like PCB congeners (PCBs 99,138,153,180, 187, 194, and 199). Similar results,

higher TSH and lower free T4 levels with increasing PCB levels, were reported in adolescents, although only in the group that had not been breast-fed (Schell et al 2008).

Established health guidelines for PCB mixtures

EPA's approach to cancer risk assessment of PCB mixtures

EPA uses a tiered approach to cancer risk assessment for PCB exposure. EPA recognized that selective bioaccumulation in the environment creates dietary PCB mixtures that differ markedly from Aroclor mixtures produced commercially. The tiers attempt to address the likely differences in toxicity and persistence of PCB mixtures. The tiers also reflect that PCB mixtures comprised mostly of congeners with more than 4 chlorines are more persistent and more carcinogenic than more lightly-chlorinated, less persistent congeners.

EPA recommends that risk assessors use a cancer slope factor of 2.0 mg/kg/d for PCB mixtures present in the food chain. This most potent assumption should also be applied to protect all early life exposures. A less potent assumption of 0.4 mg/kg-d can be used in assessments of ingestion of water soluble congeners and inhalation of evaporated congeners. A third tier (cancer slope equal to 0.07 mg/kg-day) is provided for assessment of exposure to PCB mixtures with less than one half percent congeners of 4 or more chlorines. (Cogliano 1998)

Dioxin-like congeners and Toxic Equivalency (TEQ) approach.

For those PCBs congeners that have dioxin-like toxic effects, it is useful to express PCBs exposures as dioxin "TEQs" (toxic equivalents). The TEQ is the concentration of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) that would have the same toxic activity as the PCB congener mixture. The TEF is the relative toxic potency of the congener, relative to that of TCDD. The World Health Organization has developed TEFs for mammals (including humans) for the sub-set of 7 dioxin, 10 dibenzofuran, and 12 PCB congeners that elicit aryl hydrocarbon receptor (AhR)-mediated biochemical and toxic responses similar to TCDD (Van den Berg et al. 2006). For dioxin-like PCBs, congener-specific concentrations can be converted to TCDD-TEQ using the TEFs shown in Table 25. Congener-specific TEQ values are summed and expressed as total TCDD-TEQs.

The TEQ is calculated as the sum of the products of the congener concentrations and congener Toxicity Equivalency Factors (TEF).

$TEQ = \Sigma (TEF_i \cdot C_i)$

Where:

TEF_i = Toxicity equivalency factor for congener "i"

C_i = Concentration of congener "i"

Table 25: Toxicity Equivalence Factors for PCB Congeners

Class	Congener	CASRN	Mammal Toxicity Equivalence Factor (TEF)
Co-planar PCBs	3,3',4,4'-TCB (77)	32598133	0.0001
	3,4,4',5-TCB (81)	70362504	0.0003
	3,3',4,4'-5-PeCB (126)	57465288	0.1
	3,3',4,4',5,5'-HxCB (169)	32774166	0.03
Mono-ortho PCBs	2,3,3',4,4'-PeCB (105)	32598144	0.00003
	2,3,4,4',5-PeCB (114)	74472370	0.00003
	2,3',4,4',5-PeCB (118)	31508006	0.00003
	2',3,4,4',5-PeCB (123)	65510443	0.00003
	2,3,3',4,4',5-HxCB (156)	38380084	0.00003
	2,3,3',4,4',5'-HxCB (157)	69782907	0.00003
	2,3',4,4',5,5'-HxCB (167)	52663726	0.00003
	2,3,3',4,4',5,5'-HpCB (189)	39635319	0.00003

The EPA recently set the daily level of exposure considered safe (also known as the Reference Dose or the RfD) at 0.7 picograms of dioxins per kilogram of body weight (EPA, 2012 Dioxin reassessment). This number is believed to protect against the most sensitive non-cancer endpoints observed. It is based on observations of health effects at 20 pg/kg/d in two follow-up studies conducted after an industrial accident in Seveso, Italy. Findings were reduced sperm counts in men exposed in childhood and infants with increased thyroid hormones if their mothers were exposed during pregnancy (Mocarelli et al 2008, Baccarelli et al 2008). The level set by the World Health Organization/United Nations in 2001 is about three times higher than EPAs RfD. EPA is still developing its health guidance for cancer assessment for dioxin.

Other health guidance

There are a number of health standards that address exposures to PCBs in people. For assessment of dietary intake, DOH primarily would use the EPA RfD, TEFs as described in WHO 2005, and an upper bound cancer slope factor of 2.0 mg/kg/d. For inhalation of evaporated congeners, DOH would follow EPA guidance, using the middle-tier slope factor (0.4 per (mg/kg/day)

converted to a unit risk of 1 x 10-4 per µg/m3. The corresponding ambient air concentrations are provided below.

Ambient air concentration associated with a risk of:

- Probability of 1 additional cancer in a population of 10,000 people — 1 $\mu g/m^3$
- Probability of 1 additional cancer in a population of 100,000 people — 0.1 µg/m3
- Probability of 1 additional cancer in a population of 1,000,000 people — 0.01 $\mu g/m^3$

For inhalation of an aerosol or dust contaminated with PCBs, the slope factor for "high risk and persistence" would be used instead.

Table 26: Established health regulations/guidance for PCBs

Type of exposure	Exposure Limits	Agency	date established
Total oral daily intake - chronic	Oral RfD is 0.07 µg/kg/day (Aroclor 1016) 0.02 µg/kg/day (Aroclor 1254)	EPA	2000
Total daily intake of dioxin-like chemicals (TEQ)	0.7 pg/kg/day	EPA	2012
Total daily intake of dioxin-like chemicals (TEQ)	2.3 pg/kg/day	WHO – FAO JECFA	2001
Minimal Risk Level for chronic oral intake	MRL is 0.02 ug/kg/d (Aroclor 1254)	ATSDR	2000
PCBs in specific foods	0.2-3.0 ppm in various categories of food.	FDA	1996
PCBs in edible fish entering interstate commerce	2.0 ppm	FDA	2011
PCBs in fish	Screening level of 23 ppb in fish tissue	DOH	See website
Drinking water	MCL is 0.5 µg/L (or 500 ppt). The MCL Goal is set at zero.	EPA	1992 (reviewed 2010)
Bottled water	0.5 µg/L	FDA	1999
Ambient Air	0.01 $\mu g/m^3$ based on cancer risk of 1 in 1,000,000	EPA	2000
Indoor air – schools*	0.07-0.60 $\mu g/m^3$ depending on age of children present.	EPA	2009?
Occupational air	1.0 $\mu g/m^3$	NIOSH	2000
Occupational air	1,000 $\mu g/m^3$ (Aroclor 1254); 500 $\mu g/m^3$ (Aroclor 1242)	OSHA	1998 - 29 CFR 1910.10003
Occupational air	1,000 $\mu g/m^3$ (Aroclor 1254); 500 $\mu g/m^3$ (Aroclor 1242)	ACGIH	1998

WHO-FAO JECFA: World Health Organization, Food and Agricultural Organization Joint Expert Committee on Food Additives

*EPA calculated indoor air guidance for schools that would maintain exposure levels below the RfD of 20 ng/kg/d. EPA estimate assumes average exposures through diet, water air and other sources. Residential indoor air levels would need to be lower to reflect the longer hours spent at home.

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PCB Exposures in People

PCBs are absorbed primarily from the diet and air, accumulate in fatty tissues, and are excreted, often very slowly, from the human body. PCBs are readily absorbed from the gastrointestinal tract. Absorption efficiency across the gut is higher with more chlorinated congeners. Once in the blood stream, PCBs are rapidly cleared and initially accumulate in liver and muscle tissue. In general, PCBs then redistribute to adipose tissue and skin but this varies depending on the congener (ATSDR 2000). For instance, PCB 126 is a coplanar PCB and binds very tightly to CYP1A2 and subsequently concentrates in the liver of rodent. Other highly persistent PCBs (e.g., PCB 153) are stored primarily in the adipose tissue and skin. There are also gender differences in storage of PCBs (Feeley and Jordan 1998). Metabolism of PCBs involves metabolic enzymes called cytochrome P_{450} enzymes (CYP). Specific subtypes involved in PCB metabolism are CYP1A1 and 1A2, CYP2B1 and 2B2, and CYP3A. Metabolism can lead to biologically active arene oxides and hydroxylated and methysulfonyl metabolites. Elimination of PCBs from the body is largely dependent on biotransformation of congeners to more polar metabolites. Half-lives for PCBs congeners in humans are estimated at 1.4-4.9 years for lightly chlorinated PCB 28 and 10-15 years for the more chlorinated congeners such as PCB 153, 170, and 180 (Ritter et al., 2011). Longer half-life estimates have also been reported (ATSDR 2000, Milbrath et al 2009). Because PCBs are more readily absorbed than excreted, they accumulate in the body over time.

Background exposures in the general population and developing child.

PCBs are widely detected in adipose tissue and blood of people with no occupational exposure (Lordo et al 1996, CDC 2009). The bulk of PCBs in people is stored in fat and fatty tissue and is not circulating in the blood, however, there is a dynamic equilibrium between stores in fat and concentrations in blood (ATSDR). PCB in serum is a common indicator of body burden. Most studies of PCBs in serum report lipid-adjusted measurements to correct for short-term fluctuation in circulating lipids. Earlier literature reported results as units of PCB per whole (or fresh) weight of blood and these too correlated well with health endpoints (Jacobsen JL and Jacobsen SW 1996).

Since their ban, body burdens of PCBs in the U.S. have declined. Some evidence suggests that human serum levels have decreased by more than 80% since the 1980s. (CDC 2009. Longnecker et al. 2003; Woodruff et al. 2011). Recent estimates of body burden of PCBs in the U.S. general population are available from the National Health and Nutritional Examination Study (NHANES) (CDC 2009). This survey sampled serum for 34 PCB congeners in 2001–2002 and added 4 dioxin-like PCB congeners in 2003–2004 for a total of 38 congeners. In the 2003-2004 survey, 100% of the 1866 participants sampled had detectable levels of PCBs in their serum (Patterson et al. 2009). The primary congeners detected (at median detection values) were PCB

153, 180, and 138/158. PCB 28, 74, 118, 170, and 187 were also frequently detected. Table 27 lists NHANES results. The sum of 35 PCB congeners in participants had a mean of 134.4 ng/g blood lipid (0.820 ng/g whole weight blood). Five percent of the participants sampled had a sum of PCB in blood higher than 530.7 ng/g lipid weight (3.531 ng/g whole weight) (Patterson et al 2009). The TEQ of total dioxins, furans and dioxin like PCB in the NHANES 2001-2 survey was calculated to be 30.4 pg/g lipid for the general population. The nine PCB congeners with dioxin-like properties contributed 38-41% of the TEQ depending on the age of the participant (Ferriby et al. 2007). Both studies showed that increasing PCB body burden is strongly associated with increasing age.

Table 27: Sum of 35 PCB congeners in 2003-04 NHANES survey (Patterson et al. 2009)

Age of participant	50th percentile for population (CI)	95th Percentile for population (CI)	Population sample size
12-29 years	51.2 (48.2-56.1)	139.0 (110.8-164.3)	585
20-39 years	75.4 (71.2–81.7)	226.5 (170.6-300.5)	452
40-59 years	174.4 (159.9-201.9)	470.7 (373.5-650.9)	383
60+ years	334.5 (308.7-351.8)	929.4 (752.2-1167.9)	446
Total (all ages)	131.8 (121.8-145.5)	530.7 (498.4-570.2)	1866

Serum levels in ng/g blood lipid
CI is the 95% confidence interval for the estimate of percentile in the study population

There are some broad patterns in PCB congener bioaccumulation. For instance, less chlorinated congeners are readily taken up by organisms but most are also eliminated and therefore do not bioaccumulate to a great extent. PCBs with five or more chlorines bioaccumulate readily in biological tissue. PCB congeners with two adjacent unsubstituted carbons are more easily degraded and eliminated. In fact, congeners with this substitution pattern comprised 28% of Aroclor 1260 but only composed 0.81% of the human milk PCB's (Safe et al.1985).

Greater body burdens of PCBs have been reported in people who heavily consume fish, eat a diet high in fatty marine mammals, or consume land animals such as mink and bears that eat a diet rich in fish and marine mammals. People who live or work in buildings with PCB containing joint sealants, light ballasts, and caulk have also been shown to have elevated PCB levels.

Prenatal exposure (developing child)

PCBs cross the placenta of experimental animals and humans. There was initial speculation that the placenta served as a selective barrier to PCBs because PCB levels in newborns or in cord blood at birth are lower than levels in maternal serum (Masuda et al., 1978). This has been refuted by studies such as Jacobson et al. 1984, which have shown that once PCB level is adjusted for percent lipid in the blood, there is no difference between PCB blood levels in maternal serum and cord blood at the time of birth. It appears that PCB transfer across the placenta is not specifically regulated but rather is a function of the placenta's lipid permeability (Swain, 1991).

PCBs stored in fat and fatty tissues are mobilized as serum lipids increase during the normal course of pregnancy. Median concentration of total serum lipids increased 43% and median serum levels of PCBs increased 34% between the first and third trimesters in a study of 67 women. The increase was completely explained by the increase in lipids; when results were lipid normalized there was no difference in ug PCB/g serum lipid (Longnecker et al., 1999).

The body burden of PCBs accumulated over a lifetime is thought to be the primary determinant of circulating levels of PCB during pregnancy; however, a study reported by Humphrey 1989 demonstrated that a single contaminated meal could conceivably expose a fetus to a transient peak of PCBs. In an experiment with healthy volunteers, serum concentrations of PCBs spiked immediately after volunteers ate a fish meal from the Great Lakes (fish contained 4-10 ppm PCB). Serum PCB concentration peaked at 250-500% above baseline within about 10 hours, fell sharply until 24 hours, then slowly returned to pre-meal baseline over the following week. Although critical periods of vulnerability to PCBs are not understood in detail, there is a general consensus that critical periods in pregnancy exist for developmental toxicants.
Recent estimates of serum levels in US pregnant women indicate that median level of PCB 153 was 7.8 ng/g lipid in the 2003-05 NHANES survey. This is about $1/10^{th}$ or less than the levels associated with neurodevelopmental effects in maternal- infant studies conducted in Michigan and North Carolina in the early 1980s (Longnecker et al 2003).

Exposure of Neonates via Breast milk (developing child)

Animal and human studies have documented transfer of PCBs to nursing young via breast milk. The PCB body burden of children at 4 years old is strongly related to the level of contamination in milk and duration of lactation (Swain 1991; Patandin et al., 1999; Walkowiak et al., 2001). Blood levels of PCBs in Japanese children of occupationally-exposed parents also showed a strong correlation with length of lactation (Hara, 1985). By some estimates, human infants can receive up to 10-12% of their lifetime dose from nursing (Birnbaum and Slezak, 1999).

Reported levels of PCBs in breast milk have declined since PCB production ceased (Pan et al 2009, Zietz et al 2008). A 1980 study of the general population in North Carolina reported levels from 1 to $\geq$4 mg/kg PCB in milk fat of breast milk. A more recent survey of 304 nursing women in NC during 2004-2006, women reported mean PCBs concentration in milk were 0.077 mg/kg in milk lipid (Pan et al, 2009).

Breast milk samples from 40 first-time mothers from the Pacific Northwest of the U.S. and Canada were analyzed for PBDEs and PCBs (She et al., 2007). Total PCBs were calculated by summing values of 82 separate PCB congeners and ranged from 0.049 to 0.415 mg/kg lipid.

Sources and pathways of exposure

Diet - PCBs in Food

PCBs in food are the most significant source of exposure for most people. PCBs can be highly concentrated in the fish of waters contaminated with even low levels of PCBs. The major dietary sources of PCBs are fish (especially freshwater fish that are caught in contaminated lakes or rivers), meat, and dairy products. Predator fish at the top of the food chain, as well as bottom feeding fish, tend to contain the highest PCB levels in those waters. While it appears that PCB levels are declining in the environment, PCB levels in sportfish are still high enough to lead to exposure of concern to consumers. Recent studies on fish indicate maximum concentrations of PCBs can be in the 10 to 100 parts per million in fish, with higher levels found in bottom-feeders such as carp and largescale suckers or in fish near known sources of PCB contamination. Meat and dairy products are generally much lower in PCBs with concentrations in the low parts per billion.

PCBs in freshwater fish species from Washington State

While PCB data is limited on the national level for many commonly consumed foods, many states evaluate contaminant concentrations, including PCBs in fish within their borders.

The Washington State Department of Ecology routinely conducts fish tissue monitoring as part of its Washington State Toxics Monitoring Program (WSTMP) and Total Maximum Daily Load (TMDL). Between these two programs, thousands of fish have been sampled from hundreds of sites across Washington State. Figure 25 displays the frequency distribution of total PCB tissue concentrations from fish collected across Washington State from several sources.

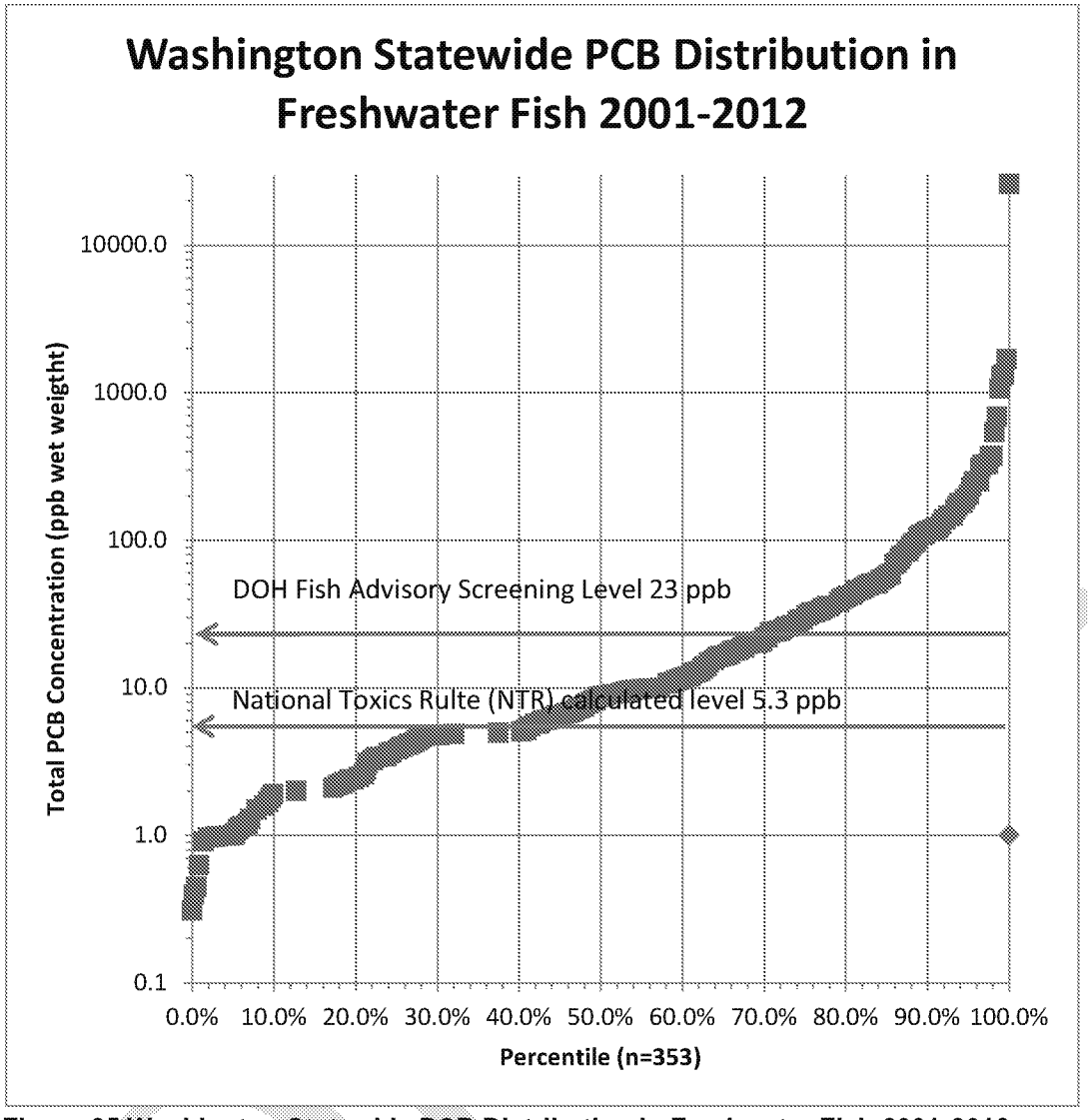


Figure 25 Washington Statewide PCB Distribution in Freshwater Fish 2001-2012

Data are from 2001-2010 total PCB fish tissue concentrations extracted from Ecology's EIM database (Seiders, 2012). Additional total PCB data are from the EPA's Upper Columbia River site investigation as reported by DOH (DOH 2012), U.S Department of Energy's 2012 assessment of contaminant data in the Mid-Columbia River (*http://www.washingtoncloisure.com/projects/environmental_protection/mission_completion/project_library/#investigation*), and fish tissue data collected by the U.S. Army Corps of Engineers near Bradford Island and the Bonneville Dam on the Columbia River (unpublished data).

DOH's screening level for consideration of a fish advisory is 23 ppb and is displayed for reference. Concentrations above the screening level would be evaluated further for possible listing in a fish advisory.

The data set displayed in Figure 25 includes 353 total PCB values that range from non-detects to greater than 26,000 ppb, with a mean and median of 123.1 ppb and 8.7 ppb, respectively. Data are highly skewed to the right due to a single outlier from bass collected near the Bonneville

Dam in Oregon. Without this data point, the mean drops to 49.6 ppb and the median value remains 8.7 ppb.

The level of 5.3 ppb PCBs calculated from the human health-based National Toxics Rule (NTR) for PCBs is designed to minimize the risk of effects occurring to human from chronic (lifetime) exposure to substances thought the ingestion of drinking water and consumption of fish obtained from surface waters. The NTR criteria, if met, will generally ensure that public health concerns do not arise, and that fish advisories are not needed. While DOH supports Ecology's use of the NTR criteria for identifying problems and controlling pollutant sources so that water quality will meet standards, DOH does not use the NTR criteria to establish fish consumption advisories. DOH establishes screening levels by using an approach similar to that outlined in EPA's *Guidance for Assessing Chemical Contaminant Data for use in Fish Advisories Vol. 1-4* for assessing mercury, PCBs, and other contaminants (EPA 2000). These guidance documents provide a framework from which states can evaluate fish tissue data to develop fish consumption advisories, based on sound science and established procedures in risk assessment, risk management, and risk communication. Neither the NRT criteria, nor the Screening Values found in the EPA guidance documents above, incorporate the varied risk management decisions essential to developing fish consumption advisories. DOH's current screening level for PCBs based is based on the recommendations from the American Heart Association that people should consume two meals of fish per week to gain the known health benefits associated with fish consumption. Applying this consumption rate, coupled with an average body weight of a person and EPA's RfD for PCBs results in a screening value of 23 ppb.

PCBs in commercially available fish in Washington State

Limited data on PCBs in commercially available fish are also available for Washington State. The primary source of this data is A DOH 2005 study of contaminants in canned tuna and other frequently consumed store bought fish purchased in Washington State grocery stores (McBride et al., 2005). In this study, PCBs (based on Aroclors concentrations) were detected in store-bought halibut, red snapper, and salmon in at least 10% of the samples collected. Salmon had the highest average PCB concentrations (31.5 ppb PCBs, total Aroclors). Additional data from the Washington State Department of Fish and Wildlife on PCB levels in Puget Sound Chinook and coho salmon were also included for this assessment (DOH 2006). A comparison of PCB concentrations in from store bought and Puget Sound fish commercially available fish can be seen in Figure 26. Of all fish species, PCB concentrations were highest in Chinook salmon collected in Puget Sound. As the data indicate, PCB levels in Chinook salmon returning to Puget Sound waters typically have higher concentrations than coastal salmon or Alaskan Chinook. The higher concentration in Puget Sound Chinook and resident Blackmouth is believed to be linked to greater residence time in areas such as Puget Sound that have greater PCB loads. The current advice from DOH regarding PCBs in Puget Sound Chinook salmon recommends that women of childbearing age and young children should eat not more than one meal per week. Most fish

species collected from grocery stores were below DOH's general population screening level of 23 ppb.

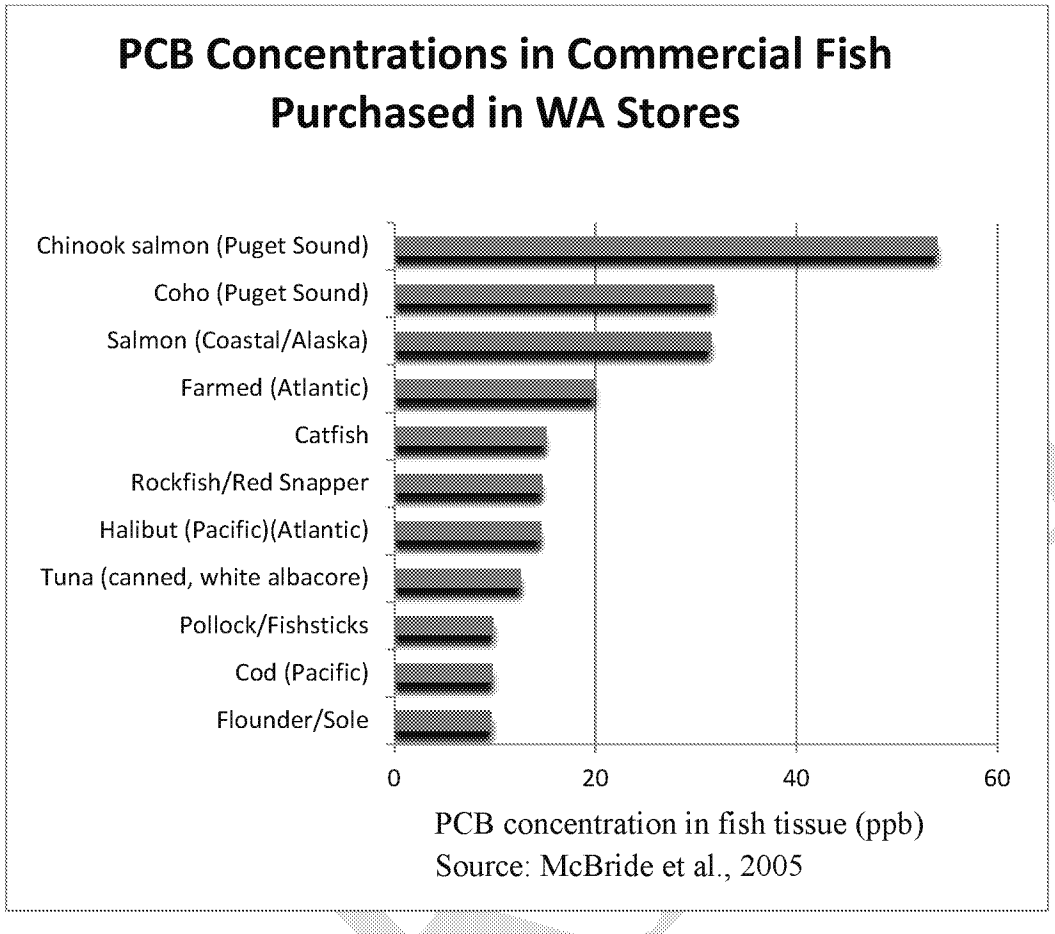


Figure 26: Mean PCB concentrations (total Aroclors) in fish collected from markets and grocery stores in Washington State and from Puget Sound.

Other dietary sources of PCBs

Humans may be exposed to small but detectable quantities of PCBs in meat and dairy products and other foods although studies that have measured PCBs in commercial food are limited. Little information is available regarding contaminant concentration in other protein sources in Washington State. PCB concentrations in fish, meat, and dairy products vary widely depending on where they are caught or grown and on processing or cooking techniques. The Federal Food and Drug Agency (FDA) limits allowable PCB concentration to 1.5 ppm in milk and other dairy products, 0.3 ppm in eggs, 3 ppm in poultry, 2 ppm in edible portions of fish and shellfish, and 0.2 ppm in infant and junior foods (FDA 21 CFR 109). In actuality, sampling for PCB concentrations in FDA's Market Basket studies between 1991 and 2003 showed PCB levels are far below these limits in a variety of prepared dishes. This section summarizes available data from various U.S. and international sources.

The Total Diet Study (TDS), sometimes called the market basket study, is an ongoing FDA program that determines levels of various contaminants and nutrients in foods. http://www.fda.gov/downloads/Food/FoodScienceResearch/TotalDietStudy/UCM184304.pdf. From this information, dietary intakes of those analytes by the U.S. population can be estimated. Since its inception in 1961 as a program to monitor for radioactive contamination of foods, the TDS has grown to encompass additional analytes, including pesticide residues, industrial chemicals, and toxic and nutrient elements. A unique aspect of the TDS is that foods are prepared as they would be consumed (table-ready) prior to analysis, so the analytical results provide the basis for realistic estimates of the dietary intake of these analytes. TDS Market Basket surveys are generally conducted four times each year, once in each of four geographic regions of the countries. Food samples are purchased from supermarkets, grocery stores and fast food restaurants in three cities in the region and are shipped to a central laboratory. The foods are then prepared table-ready and the three samples are combined to form a single analytical composite for each food. For each survey, samples of food are collected over a 5-week period in three cities in the region. The following graph depicts results encompassing 1991-93 through 2003-04 PCB results analyzed in 26 separate food items. Total PCB concentrations are expressed as Aroclor equivalents, rather than as the sum of results from congener-specific measurements. Mean PCB concentrations ranged from 0.09 ppb for chicken potpie to 24.4 ppb for salmon. The average concentration for the 26 food items was 1.7 ppb.

PCB concentrations in foods from the market basket survey are much lower than previously reported by the Puget Sound Action Team in 2007 and cited by Ecology's Toxics Cleanup Program (Ecology 2012d). PCB levels in foods reported by the Puget Sound Action Team were based on a very small sample size of 1 or 2. The current summary of PCB levels in common foods presented in Table 28 of as reported by FDA were based on much larger sample sizes, with average samples sizes greater than 40 resulting in more robust, representative PCB levels.

Table 28: Measured PCB Levels as Reported by USFDA

Food Description	Sample Size	Results		
		Concentration (ppb)		Detection Frequency %
		Mean	Maximum	
Chicken potpie, frozen, heated	44	0.09	4	2.3
Candy, caramels	40	0.15	6	2.5
Beef roast, chuck, oven-roasted	44	0.23	10	2.3
Pork roast, loin, oven-roasted	44	0.23	10	2.3
Lamb chop, pan-cooked w/ oil	44	0.23	10	2.3
Chicken, drumsticks and breasts, breaded and fried, homemade	40	0.23	9	2.5
Corn/hominy grits, enriched, cooked	44	0.23	10	2.3
Cornbread, homemade	44	0.23	10	2.3
Biscuits, refrigerated-type, baked	44	0.23	10	2.3
Raisins	44	0.23	10	2.3
English muffin, plain, toasted	44	0.23	10	2.3
Veal cutlet, pan-cooked	40	0.25	10	2.5
Crackers, butter-type	44	0.25	11	2.3
Pork chop, pan-cooked w/ oil	44	0.45	20	2.3
Meatloaf, beef, homemade	44	0.45	20	2.3
Beef (loin/sirloin) steak, pan cooked with added fat	40	0.5	20	2.5
Pancakes made from mix with addition of egg, milk, and oil	40	0.5	20	2.5
Baby food, vegetables and chicken	44	0.68	30	2.3
Brown gravy, homemade	40	0.75	30	2.5
Tuna, canned in oil, drained	40	1.0	40	2.5
Eggs, fried with added fat	40	1.23	39	5.0
Chicken breast, oven-roasted (skin removed)	44	1.36	30	4.5
Popcorn, popped in oil	40	1.7	30	10.0
Butter, regular (salted)	44	3.18	120	4.5
Catfish, pan-cooked w/ oil	4	4.25	17	25.0
Salmon, steaks/fillets, baked	24	24.38	55	91.7

Table summarizes PCB analytical results of food from the Food and Drug Administration's Total Diet Study program. The information pertains to Total Diet Study market baskets 1991-93 through 2003-04. Statistics were calculated using value of 0 foe results below the detection limit. This document is available on the internet at: http://www.cfsan.fda.gov/~comm/tds-res.html.

In addition to the USFDA information, much of what is known about non-lipid normalized PCB concentrations in foods in the U.S. over the past decade and a half have been measured by Arnold Schecter and colleagues at the University of Texas in Dallas. These studies have focused on common foods in the American diet that were collected throughout the country. The following summarizes those individual studies and a compilation of the data is presented in Table 29.

Schecter et al. (1997) pooled food samples collected from grocery stores across the U.S. and measured 15 different PCB congeners, including eight coplanar PCBs; three mono-ortho PCBs, and four di-ortho PCBs. A total of 90 individual food specimens were pooled into 12 different food types (e.g. cheese, beef) and analyzed for dioxins, dibenzofurans, and PCBs. Based on a conversion of the measured congeners, the authors conclude that PCBs contribute significantly to total TEQ values in 8 out of 12 sample types.

Schecter and Li (1997) measured dioxin-like PCBs in U.S. fast food purchased at 5 cities across the U.S. Samples were pooled by type and tested for seven mono- and di-ortho PCBs. Total PCB levels ranged from 0.957 ppb (McDonalds Big Mac) up to 1.180 ppb (Pizza Hut Personal Pan Supreme w/ anchovies). The authors estimate that fast food accounts for roughly 16.7 - 52.7% of the total daily TEQ of dioxin-like compounds.

Schecter et al. (1998) analyzed both cooked and uncooked samples of beef, bacon, and catfish from a supermarket in Binghamton, New York. A total of 5 cooked, and 4 uncooked samples of each type of meat were analyzed for dioxins, dibenzofurans, and three dioxin-like PCBs (77, 126, 169). Total PCB concentration for each food type ranged from 1.028 ppb (wet weight) (uncooked hamburger) to 5.370 ppb (cooked bacon). Broiling each type of sample resulted in a 50% decrease on average in total PCDD, PCDF, and coplanar PCB TEQ. However, broiling of hamburger resulted in an increase of total coplanar PCB concentration of 10.4%; broiling bacon resulted in an increase of 75.7% of total coplanar PCB concentration. The authors conclude that final concentrations (pg TEQ/kg) of PCDDs, PCDFs, and coplanar PCBs in broiled foods cannot be accurately predicted from raw samples due to variances in cooking method.

Schecter et al. (2002) analyzed a total of 72 meat baby food samples purchased from grocery stores across the U.S. (Illinois, Nebraska, California, Georgia, New York, Pennsylvania, and Maryland). Three to six samples (200g each) were purchased from each state, and analyzed for dioxins and three coplanar PCB congeners (77, 126, and 159). Total PCBs for each food sample type range from 0.579 ppb (wet weight) (lamb) to 2.280 ppb (chicken). Converted TEQ concentration for total PCBs for each food type ranged from 17.6 (lamb) to 95.9 (beef). The authors note that for the turkey, beef, lamb, and ham samples, total PCBs contributed more to total TEQ values than did the PCDD/PCDF values.

Schecter et al. (2010) study expanded their previous studies of persistent organic pollutants contamination, including PCBs in composite U.S. food samples collected in Dallas, Texas. showed that PCBs were not detected in any meats except hamburger, in any fish except salmon and canned sardines, or in any dairy products or eggs.

Overall, Schecter and colleagues have shown that the PCB levels in foods common in the U.S. are typically low relative to freshwater fish species collected in Washington State. PCB levels in foods other than fish are generally in the low single digit parts per billion range whereas freshwater and marine fish species one, two, and sometimes three orders of magnitude higher. Even when beef, chicken, and pork consumption rates are greater than fish consumption rates, the overall exposure pathway that people have to PCBs is dominated by the consumption of fish.

Table 29: Level of PCBs in U.S. foods (1994 – 2009)

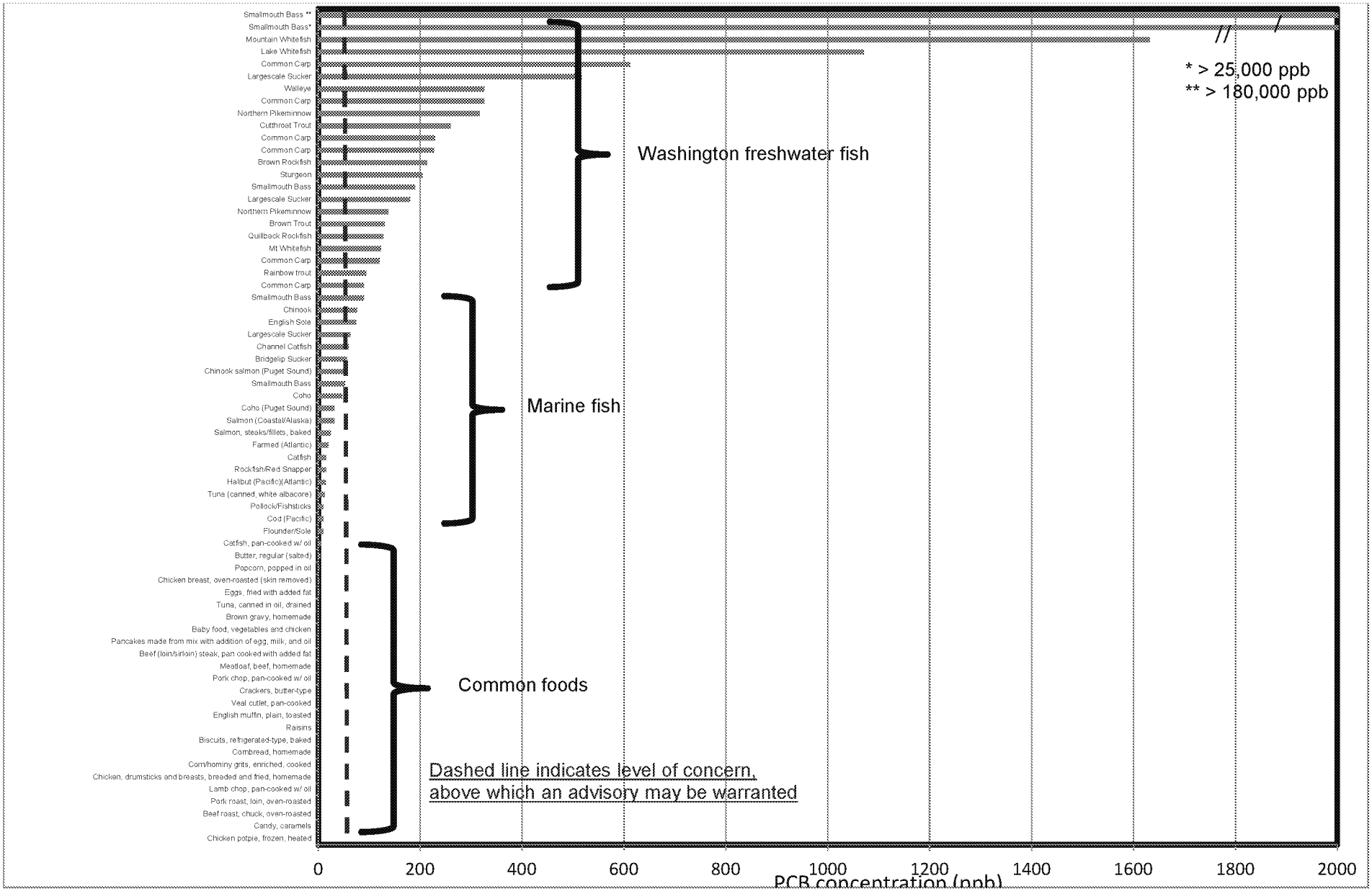
Location (date)	Type of Sample	PCB congeners	Food (sample size)	Total PCB concentration ppb (wet weight)	Reference
Across U.S. (1995)	Grocery Stores	15 total, including 8 coplanar, 3 mono-ortho, and 4 di-ortho PCB congeners	Beef (5 pooled)	Total coplanar 0.0428 ng/g; mono-ortho 0.344 ng/g; di-ortho 0.593 ng/g **Total 0.980 ppb**	Schecter et al. 1997
			Chicken (4 pooled)	Total coplanar 0.132 ng/g; mono- ortho 0.403 ng/g; di-ortho 0.505 ng/g **Total 1.04 ppb**	
			Pork (5 pooled)	Total coplanar 0.182 ng/g; mono-ortho 0.375 ng/g; di-ortho 0.322 ng/g **Total 0.879 ppb**	
			Hot dog/bologna (2 pooled)	Total coplanar 0.156 ng/g; mono-ortho 1.500 ng/g; di-ortho 1.871 ng/g **Total 3.027 ppb**	
			Eggs (3 pooled)	Total coplanar 0.0006 ng/g; mono-ortho 0.064 ng/g; di-ortho 0.147 ng/g **Total 0.212 ppb**	
			Cheese (5 pooled)	Total coplanar 0.0017 ng/g; mono-ortho 0.240 ng/g; di-ortho 0.342 ng/g **Total 0.584 ppb**	
			Butter (2 pooled)	Total coplanar 0.004 ng/g; mono-ortho 1.150 ng/g; di-ortho 2.080 ng/g **Total 3.23 ppb**	
			Ice cream (5 pooled)	Total coplanar 0.0001 ng/g; mono- ortho and di-ortho ND **Total 0.0001 ppb**	
			Milk (5 pooled)	Total coplanar 0.0004 ng/g; mono and di-ortho ND **Total 0.0004 ppb**	
			Vegan diet (1 pooled)	Total coplanar 0.0002 ng/g; mono-ortho 0.015 ng/g; di-ortho 0.144 ng/g **Total 0.159 ppb**	
Across U.S. (1995)	Fast Food Restaurants	PCBs 105, 118,156,128,138,153, 180	Hamburger, McDonalds Big Mac (5)	mono & di-ortho total 0.957 ppb	Schecter and Li 1997
			Pizza, Pizza Hut Supreme (5)	mono & di-ortho total 1.180 ppb	
			Chicken, KFC Original Recipe (5)	mono & di-ortho total 1.170 ppb	
Binghamton, NY (1996)	Grocery Stores	Coplanar PCBs 77,126, 169	Hamburger, cooked (5)	Mean 1.401; range 1.204-1.601 ppb	Schecter et al. 1998
			Hamburger, uncooked (4)	Mean 1.270; range 1.028-1.736 ppb	
			Bacon, cooked (5)	Mean 2.734; range 1.722-5.370 ppb	
			Bacon, uncooked (4)	Mean 1.556; range 1.205-1.971 ppb	
			Catfish, cooked (4)	Mean 3.188; range 1.945- 3.963 ppb	
			Catfish, uncooked (4)	Mean 4.691; range 2.200-6.387 ppb	
Across U.S. (IL, NE, CA, GA, NY, PA, MD) (1998)	Baby Food Grocery Stores	PCBs 77, 126, 159	Chicken	Range 0.883-0.228 ppb	Schecter et al. 2002
			Turkey	Range 0.144-0.160 ppb	
			Beef	Range 0.150-0.225 ppb	
			Lamb	Range 0.579-0.844 ppb	
			Ham	0.771 ppb	
Dallas, TX (2009)	Supermarkets	PCBs, 52, 101, 118, 138, 153, 180	Hambuger	PCB-153 1.2 ppb; PCB-180 0.21 ppb	Schecter et al. 2010
			Salmon	PCB-52 0.28 ppb; PCB-101 0.51 ppb; PCB-118 0.43 ppb; PCB-138 0.93 ppb; PCB-153 1.21 ppb; PCB-180 0.44 ppb	
			Canned Sardines	PCB-52 0.28 ppb; PCB-101 0.67 ppb; PCB-118 0.80 ppb; PCB-138 1.80 ppb; PCB-153 1.83 ppb; PCB-180 0.49 ppb	
			Bacon	Non-detected	
			Turkey	Non-detected	
			Sausages	Non-detected	
			Ham	Non-detected	
			Chicken breast	Non-detected	
			Roast beef	Non-detected	
			Canned chili	Non-detected	
			Catfish fillet	Non-detected	
			Tilapia	Non-detected	
			Cod	Non-detected	
			Frozen fish sticks	Non-detected	
			Butter	Non-detected	
			American cheese	Non-detected	
			Other cheese	Non-detected	
			Whole milk	Non-detected	
			Yogurt	Non-detected	
			Cream cheese	Non-detected	
			Eggs	Non-detected	

A compilation of the three primary data sets on PCB levels in foods (Washington State freshwater fish 2001-2012; Washington commercial fish, and U.S. FDA's Total Diet Study) gives a clearer view of the relative differences in PCB concentrations in these three distinct food

categories (sport caught fish, store-bought fish, and other food items other than fish) as seen in Table 30.

With few exceptions, freshwater fish species (a subset of the state's freshwater fish PCB data is shown in Figure 25 that represents those species associated with DOH fish advisories due to PCB levels) have the highest PCB levels. Mean PCB concentration of all freshwater fish for which DOH has issued fish consumption advisories is over 150 times higher than the mean PCB concentration reported in common food items. Freshwater fish species are over 10 times higher than PCB concentrations measured in commercially available fish in Washington State stores. Commercially purchased fish PCB levels are also greater than mean PCB concentrations of other commercially available foods tested by a factor of ten. Such comparisons illustrates the relative contribution and importance that freshwater fish species can contribute to one an individual's overall PCB exposure, particularly for high fish consumers.

Table 30 PCB Concentrations (ppb) in Sportcaught Fish Collected in Washington, Commercial Fish Purchased in Washington, & Common Foods



Data sources: Ecology EIM database, U.S. Dept. of Energy, DOH commercial fish study, FDA Total Diet Study 1991-2006

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Dioxin-Like PCBs in food

As mentioned above, food is the major route for human exposure to PCBs but also other dioxin-like compounds (referred to collectively as DLCs). Most DLCs in foods are contained in the lipid component of foods of animal origin. While DLC exposure through fruits, vegetables, and grains also occurs, it is thought to result primarily from the adhesion of soil to plant material (NAS 2003).

The 2003 publication of National Academy of Science (NAS 2003) "Dioxins and Dioxin-Like Compounds in the Food Supply" provided a comprehensive compilation of data on dietary exposure to dioxin and dioxin-like compounds including PCBs. Estimates of exposure are based on data on concentrations of dioxins and dioxins-like compounds measured in foods and dietary consumption habits of those foods. The dioxin and PCB food concentration data was based on the US Food and Drug Administration's Total Diet Study (FDA 2006). The Total Diet Study is an ongoing evaluation of contaminants in food and has been in place since the early 1960s. Estimates of food consumption rates were based on Continuing Survey of Food Intakes by Individuals which was a survey conducted between 1994 and 1996 and in 1998 to evaluate consumption rates of foods. More current estimates of dioxin and dioxin-like compounds is available up through 2004.

Due primarily to the high cost per sample to analyze DLCs, there is relatively little information on the DLC content of the U.S. food supply. Recently however, FDA conducted DLC analyses for selected foods collected as market basket samples in the TDS. The TDS survey samples foods purchased by FDA personnel from supermarkets or grocery stores four times per year; one sample is collected from each of three cities from each of four geographic regions. Each market basket contains similar foods purchased in the three cities in a given region. The market basket food samples are then prepared as for consumption, and the three samples of a food from a region are composited into a single sample, prepared in duplicate, and analyzed for DLCs.

The NAS report identifies that dietary sources of animal fat are by far the largest source of dioxin exposure to the general population, with 90% of total exposure being due to consumption of food – namely animal products and their associated animal fats (beef, pork chicken, fish, fats (butter), and dairy products.

Published literature on PCB concentrations in food is more limited than dioxin. Since coplanar PCBs act toxicologically like dioxins, all recent evaluations of dioxin-like compound exposure include some estimate of coplanar PCB exposure (e.g., NAS 2003, EPA 2000). A common "rule of thumb" cited in NAS (2003) is to double dioxin exposure to estimate total exposure to dioxins and coplanar PCBs. While this estimate is qualitative, NAS cited studies that reported estimates of coplanar PCB contribution to total dioxin-TEQs ranging from 37% to 57%, and concluded that 50% is a reasonable estimate to apply in general.

EPA's 2000 Draft Dioxin Reassessment (EPA 2000) summarized the available data on background concentrations in foods for the United States. Using that data and standard assumptions for intake or contact rates, they developed an estimate of general background exposure to coplanar PCBs. The estimates assume concentrations in food reported as nondetected are present at ½ the detection limit. EPA estimated an adult general population background exposure of dioxins and furans at 0.61 pg/kg/day, and an adult general population background exposure from coplanar PCBs was estimated at 0.34 pg/kg/day. Based on EPA's analysis, coplanar PCBs account for approximately one-third of total dioxin-TEQs, which is in the low range of values reported (Smith and Frohmberg, 2008).

Given EPA's estimate for dioxin exposure in the general adult population (0.61 pg/kg/day) is roughly equivalent to the dioxin exposure estimates presented for the sensitive population in the NAS report for pregnant women (0.64 pg/kg/day), it is appropriate to use EPA's general adult population estimate for coplanar PCB-TEQ intake for pregnant women as well (i.e., 0.34 pg/kg/day). Moreover, given that coplanar PCBs are generally found in food samples at concentrations above the detection limits of laboratory analysis, this estimate is valid regardless of assumptions regarding treatment of samples with concentrations reported as non-detect.

Total estimates of dioxin TEQs (i.e., dioxins, furans, and coplanar PCBs) range from 0.72 to 0.98 pg/kg/day, depending of treatment of data reported as non-detect (Table 31). The estimate of 0.98 pg/kg/day is used as an estimate of background dietary exposure to dioxin TEQs. This estimate suggests less than 20% of the ADI (1 pg/kg/day) may be available for apportioning to sport fish consumption. However, it has been the policy of EPA both with drinking water guidelines and ambient water quality criteria to set a floor of 20% for relative source contribution. The 20 percent floor has been traditionally rationalized to prevent a situation where small fractional exposures are being controlled. That is, below that point, it is more appropriate to reduce other sources of exposure, rather than promulgating standards or guidelines for *de minimus* reductions in overall exposure (EPA, 2000).

Table 31: Estimates of Background Dietary Exposure to Dioxins and Coplanar PCBs on a Toxic Equivalents (TEQs) Basis.

Chemical	Estimated Exposure Assuming NDs = 0 (pg/kg/day)	Estimated Exposure Assuming NDs = 1/2 DL (pg/kg/day)
Dioxins/Furans TEQs	0.38	0.64
Coplanar PCB TEQs	0.34	0.34
Total TEQ	0.72	0.98
% Contribution of Coplanar PCBs to Total TEQs	47%	35%
EPA RfD for dioxin (non-cancer endpoints)	0.7 pg/kg/d	

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(Source: Smith and Frohmberg, 2008)
ND = non-detected

Consumers of Marine Mammals

Some populations in Washington State consume larger than average amounts of fish and shellfish and may occasionally consume marine mammals. Although these Tribal populations have not been studied for their body burden of PCBs, we know that other populations with diets rich in fish and marine mammals have elevated PCB body burdens. Inuit women from Arctic Quebec have higher body burdens related to their heavy consumption of fish and marine mammals (e.g., seal, beluga whale, walrus). Sampling in 1989 showed that the sum of 10 PCB congeners in breast milk was 7 times greater in Inuit women than that measured in the general population of southern Quebec (Dewailly et al. 1993). More recent sampling found persistent elevations relative to the general population: mean concentrations of 2.9 ppm in breast milk fat for Inuit vs. 0.52 ppm in general population (Ayotte et al 1997). Newborns in the Inuit population had estimated average concentrations of PCBs between 0.3 and 2.0 ug/L cord blood. (Muckle et al 1998).

People living in the Faroe Islands have also been shown to have relatively high body burdens of PCBs from their diet of pilot whale blubber and meat, fish, seabirds, and bird eggs (Fängström et al. 2002). The median sum of 18 PCB congeners in serum of 15 pregnant women who reported moderate to high amounts of pilot whale blubber was 5.9 ppm lipid weight in serum (range of 0.28 – 22.0 ppm lipid weight) (Fängström et al. 2002). Newborns in this population (n = 435) had median PCB concentration in cord tissue of 1.02 ppm lipid (Grandjean et al. 2001).

PCBs in Ambient Air

PCBs with fewer chlorines can volatilize from water, soil, or contaminated materials and effect local air concentrations (ATSDR 2000, Carlson and Hites 2005, Du et al. 2009). They can also be carried long distances by global air currents and have been detected in remote national parks and polar research stations where no local sources exist (national park study, Choi et al. 2008). Heavier PCBs are not volatile but can contaminate air when adhered to demolition dust, wind-blown dust, and airborne particulate. Inhalation was thought to be the primary pathway of occupational exposure to PCBs historically but was largely ignored for general population exposures until recently. PCB air monitoring started in Chicago in 1995 and found surprising PCB concentrations in urban air. Hu et al 2008 measured 209 PCB congeners in Chicago area air with a range of the total PCB concentration from 0.075 to 5.500 ng/m3 and the annual average of 0.835 ng/m3. PCB levels were highest on hot summer days and approached EPA “de minimus”

cancer risk estimate for chronic inhalation of evaporated PCB congeners[11]. Similar air concentrations results have been reported from the Philadelphia area (Du et al 2009) and Cleveland, OH (Basu et al. 2009). Lower levels (approximately 45-200 pg/g) have been detected in polar regions (Choi et al 2008) and in various remote locations around the Great lakes region (Basu et al. 2009).

In each of the studies, PCB 11 was detected and was occasionally a major component of total PCB detected in air. PCB11 was not a component of PCB commercial oils (Schultz et al, Frame et al, Basu et al) and is a possible but unlikely environmental breakdown product of heavier PCBs (Zanaroli et al 2006). In air monitoring studies, PCB 11 did not correlate well with concentrations other PCB congeners suggesting a unique source. Investigations into the source of PCB 11 point to contaminated pigments and dyes used to color commercial paints and to print colored paper, cardboard, and plastic packaging. (Hu and Hornbuckle 2010; Rodenberg et al 2010).

Only limited air sampling for PCBs has been conducted in Washington State. Bulk air deposition samplers have been used to estimate the load to Puget Sound soils and water surfaces. (https://fortress.wa.gov/ecy/publications/publications/1002012appendixg.pdf; http://your.kingcounty.gov/dnrp/library/wastewater/iw/SourceControl/LDW_PDS_R1-R22_Monitoring_Report-Final.pdf). These results are not adequate for estimating inhalation exposure for health risk assessment because the lighter gas phase PCBs would be largely missed by these samplers.

One EPA pilot study analyzed air samples collected in year 2000 from rural areas of the U.S. for 6 PCBs that are considered dioxin-like. This study included one site on the Olympic Peninsula in Washington. PCB 118 was the most common dioxin-like PCB detected (0.337 pg/m3). PCB 105 was detected at 0.115 pg/m3, PCB 156/7 were detected at 19.7 ft/m3, 77 was detected at 16 fg/m3, and PCB 126 and 169 were detected at 1 fg/m3 or less (EPA 2007).

PCBs in Indoor air

PCBs were used as plasticizers and flame retardants in building materials such as some elastic caulks, joint sealing compounds for brick and masonry buildings, exterior paints, window glazing, ceiling tile coatings, and some floor finishes sold in the 1950-1970s. PCBs were also widely used in fluorescent lighting ballasts installed during this same period. In different investigations since 1980, these materials have been identified as sources of elevated PCB levels in air in schools, office buildings, large apartment complexes, and other buildings. A few examples are listed below.

[11] EPA estimates that, if an individual were to continuously breathe air containing PCBs at an average of 10,000 pg/m3 over his or her entire lifetime, that person would theoretically have no more than a one-in-a-million increased chance of developing cancer as a direct result.

EPA investigated PCB levels at six unoccupied schools in NY that were scheduled for major renovation or demolition and were suspected of containing PCB sources (EPA 2012a). EPA measured PCBs in air and surface wipes in the buildings and estimated student exposures before and after PCB remediation. EPA estimated doses for a average student could have been 0.022 ug/kg/day before remediation and 0.007 ug/kg/d after. Estimates of from higher exposure scenarios were 0.041 ug/kg/day before remediation and 0.012 ug/kg/day after. PCB light ballasts and caulk were considered the primary PCB sources in the schools and inhalation the primary exposure route. Remediation reduced estimated exposure by approximately two thirds. EPA paid for congener specific PCB analysis in one of the 6 schools. Average indoor air concentration of total PCBs in air was 500 ng/m3, the average TEQ of dioxin-like congeners in air was 0.788 pg/m3. (EPA 2012a). EPA research associated with this project confirmed that caulk with high levels of PCBs caused elevated PCB in the surrounding air, that light ballasts emit PCBs at normal operating temperatures even when there was no visible liquid leaking, that caulk with low levels of PCBs can be encapsulated to reduce emissions, and that a special treatment system can be effective in removing PCBs from thin surfaces such as wall paint (EPA 2013). In December 2010, EPA released national guidance recommending that schools remove all PCB-containing lighting ballasts. These lighting systems have outlived their intended life span and are at higher risk for failing and releasing PCBs.
http://www.epa.gov/epawaste/hazard/tsd/pcbs/pubs/ballasts.htm

Elastic joint sealants containing PCBs were found to be the source of elevated PCBs in indoor air at 29 sampling sites in various public buildings in Switzerland (Kohler et al 2002). In most cases the indoor air levels of PCBs were below 1500 ng/m3 but levels up to 4200 ng/m3 were detected. As a comparison, this study reported air levels of 13,000 ng/m3 PCB at an industrial building that formerly produced transformers. PCB congeners 28 and 52, used as indicators for the more volatile PCBs, predominated in all air samples. Dioxin-like PCBs were also measured (primarily PCB 118 and 105) and the TEQ was calculated using WHO 1998 TEFs. They found that the ratio of total PCB to dioxin-like PCBs was consistent for airborne PCBs from joint sealants and that air levels of 1000 ng/m3 total PCBs corresponded to a 1.2 pg/m3 of dioxin-like PCBs. (Kohler et al 2002)

Joint sealants were also the source of PCB contamination in a public building in Germany (Schettgen et al 2012). Investigations included air measurements and biomonitoring of people who worked in the building. Workers from an uncontaminated building served as controls. Median air levels for total PCBs were reported as 1740 ng/m3 with a maximum of 4280 ng/m3. Exposed workers had significantly higher blood levels of the more volatile PCBs (28, 52, 101 and the dioxin-like congeners 105 and 118) but not heavier PCBs which constitute the bulk of human body burden and are taken up primarily in the diet (PCB 138, 153, or 180). The calculated TEQ for dioxin-like congeners did not differ statistically between the groups. Follow-up monitoring of three people who were removed from the building demonstrated that levels of PCB 28, 52, and 101 declined steadily after removal and that the biological half-lives were 4.5 ±

0.9 years for PCB 28, 1.3 ± 0.1 years for PCB 52, and 2.8 ± 0.7 years for PCB 101 (Schettgen et al 2012). Longer retention of PCB 28 in the body may explain why PCB 52 predominated in air samples but PCB 28 predominated in serum samples.

Liebel et al. 2004 reported significantly higher median serum concentrations for PCBs 28, 52, and 101 in 377 children from the contaminated school in Germany compared to 218 students attending an uncontaminated school. There was a significant positive association between years spent at the contaminated school and serum levels of the combined lower chlorinated congeners. Air levels measured in multiple locations over 2 years in the school building ranged 4-600 ng/m3 for PCB 28, 38-2300 ng/m3 for PCB 52, and 3-1100 ng/m3 for PCB 101. Very little PCB 138, 153 or 180 were detected in air sampling. The authors calculated total PCB in air over the 2 year period to be 690- 20,800 ng/m3 (mean 2044 ng/m3) based on measurement of 6 indicator congeners times 5. When PCB congeners associated with dietary intake were considered, there was no statistically significant difference between overall PCB body burden in students from the two schools. Nor was there a detectable difference in a survey of children's subjective symptoms.

Frederiksen et al 2012 reported that mean PCB air levels in Danish multiunit housing was 1030 ng/m3 (range 168-3843 ng/m3) in apartments that contained PCB in elastic sealants verses a mean of 6.03 ng/m3 in apartments sealed with PCB-free sealants. PCB sealants contained up 20% (221,680 ppm) PCB and were the primary determinant of indoor PCB levels. A survey of residents about their adherence to advice about minimizing their exposure showed that frequent ventilation, vacuuming, dusting, and floor washing were associated with lower indoor air levels.

Local examples of indoor air PCB investigations

In 2009, PCBs were discovered in chipping exterior paint on the former Rainier Brewery in Seattle at concentrations over 10,000 ppm PCB. This 4.5 acre site now houses mixed residential, restaurant, and business spaces. Paint chips were suspected to be the source of elevated PCBs in a nearby storm water collection area. In 2010, sampling by EPA detected PCBs in indoor air in some office areas (10-28 ng/m3) and in an outside stairwell that had been enclosed with the exterior paint intact (52 ng/m3). Sampling also detected PCBs in vacuum dust at concentrations between 1.4 – 15.6 ppm in residential and office spaces, 3.4-36 ppm in storage and warehouse areas, and 470 ppm in stairwell dust. DOH concluded that there was a very low to insignificant increase in cancer risk associated with the levels detected. Recommendations for mitigation included removing all paint with more than 50 ppm PCB (as required by law), warning occupants to avoid regular use of the external stairwell until remediation could take place, and adopting cleaning techniques that would reduce potential for human exposure (DOH 2013).

In 2010, PCBs were detected at high levels (up to 150,000 ppm) in exterior window caulking in the top 3 floors of a 5-story building in Seattle, WA. PCBs were also detected on the exterior window glass and nearby pavement. The building was built in 1971 and ballasts in the

fluorescent lighting also may have contained PCB oils. The assessment of PCBs was part of the King County's hazard identification prior to building demolition. Indoor air concentrations of PCBs were below the detection limit of 10 ng/m3. Sampling detected no PCBs on interior surfaces such as desktops, file cabinets, heater, refrigerator, door trims, and vinyl floors. Interior window sills contained dust ranging from non-detectable to 9.6 µg/100cm2 of PCBs. Carpet and air handling system contained bulk dust ranging from 0.46 to 9.7 ppm of PCBs and was the only type of sample which exceeded health screening levels (0.4-1 ppm). Health evaluation concluded that the cancer and non-cancer risks were insignificant given the limited uses of the building (DOH 2011).

It appears that PCBs in older building materials can elevate PCBs in indoor air and dust and cause higher body burden of certain PCB congeners in the bodies of people living or working in these buildings. In some cases the detected air concentrations were high enough to exceed residential or occupational health guidelines. In the EPA investigation into older schools in New York, indoor air levels frequently exceeded EPA health guidance for schools of 70-600 ng/m3 depending on the age of the children present. EPA requires caulk with more than 50ppm of PCBs to be removed.

Other Environmental Exposures

Small amounts of PCBs can be found in almost all soil surfaces and sediments. Most soil levels of PCBs are less than 10-40 ng/g (ppb) but soil at hazardous waste sites may be much higher. In water, a small amount of PCB may remain dissolved but most tends to stick to organic particles and sediments or evaporate from the water surface. EPA set a maximum contaminant level of 0.5 ppb for PCBs in drinking water (ATSDR 2000).

Indoor dust can bind to PCBs from indoor sources and present an inhalation or ingestion pathway for people. A 2006 survey of PCBs in residential settings reported median dust concentrations to be 200 ng/g dust (ppb) in a small set of Texas homes and 260 ng/g in Toronto homes. Maximum detected was 820 ng/g (Harrad et al 2009). While ingestion of house dust is a minor contributor to adult exposures, it can be a significant contributor to toddler exposures. Dust intake is also associated with higher molecular weight PCBs that are more bioaccumulative.

Contact with PCB in old paint, caulk or fluids leaking from capacitors can lead to skin absorption or ingestion of PCBs. It is important to wear protective clothing gloves and respiratory protection if repairing or handling equipment like light ballasts that may have PCBs in them.

Occupational exposures

Before their ban, workers who handled commercial PCB mixtures during the manufacture of transformers and electrical capacitors were found to have high body burdens of PCBs. Workers

in two U.S. electrical capacitor manufacturing and repair plants had blood plasma levels up to 546 ppb of Aroclor 1254 and up to 2530 ppb of Aroclor 1248 (Wolff et al., 1982). Adipose samples in these same U.S. workers also showed elevated PCBs of up to 165 ppm Aroclor 1254 and up to 414 ppm Aroclor 1248 (Wolff et al 1982, Wolff 1985). A number of occupational cohorts of PCB exposure workers have been followed over time for cancer incidence and cause of mortality. The most consistent results are higher incidence of liver and bile duct cancer and melanoma (NTP 2011, Lauby-Secretan et al. 2013).

Current occupational exposures can come from exposure to leaking electrical equipment made before 1977, from PCB abatement programs, or during demolition or recycling of PCB-contaminated structures and equipment.

Herrick et al 2007, conducted biomonitoring for 54 PCB congeners in a small group of construction workers with a history of removing PCB caulk from buildings in the greater Boston area. The workers had higher proportions of lighter PCB congeners (PCB 6-74) in their serum than a reference population of men who sought health care in the Boston area. Specifically the mean congener concentrations in construction workers were more than five times higher than the reference population for PCB 6, 16, 26, 33, 37, 41, 70, 97, and 136. One worker, who was actively involved with PCB products at the time of blood collection, had 25% of his body burden comprised of the lighter PCBs compared to 7% of the PCB serum levels in the referent population.

Wingfors et al. 2006 collected blood samples from 36 workers directly involved in abating PCB sealants in Sweden. These were compared in a biomonitoring study to 33 age- and sex-matched construction workers who did not work in the abatement program. The exposed workers had PCB serum levels (sum of 19 congeners) that were twice as high as the controls (geometric mean of exposed workers were 575 ng/g lipid compared to 267 ng/g for the controls). The PCB congener patterns also differed between the workers and the controls, with much higher levels of many less chlorinated PCBs in the exposed workers, compared to the controls. The authors concluded that PCBs 56/60, 66, were good markers of general occupational exposure; 44, 70, and 110 were good markers for recent occupational exposures; and 153 and 180 reflected background (dietary) exposure. Follow-up samples taken 10 months later showed that serum concentrations of rapidly excreted congeners (PCB 52, 44, 70, and 110) declined after workers were given information about protecting themselves from exposure.

Washington State Health Advice

Fish consumption is the primary exposure pathway that most Washingtonians have to many Persistent, Bioaccumulative Toxics (PBTs). Many PBTs such as PCBs, DDT, and mercury are linked to a variety of adverse health effects (e.g. neurological, developmental, immunological, and cancer). The paradox of consuming fish is that it also known to be one of the healthiest

forms of protein due in part to the high levels of omega-3 fatty acids that have been associated with a variety of positive health outcomes (e.g. prevention of heart disease, inflammation, arteriosclerosis, and cognitive development). Results from the most recent Behavioral Risk Factor Surveillance System (BRFSS) conducted by DOH indicate that nearly three quarters of the adult general population in Washington State consume fish. Washington State is also the home of numerous federally recognized tribes whose fish consumption rates are often well above that of the general population (Ecology 2013). Additionally, there are other high fish consuming populations within the state including Asian and Pacific Islanders and sports fishers.

Because of potential exposure to PBTs to fish consuming populations, DOH collaborates with numerous state and federal agencies on the collection and analysis of contaminants in fish. DOH's role is to evaluate fish contaminant levels in fish tissue for potential public health impacts and to convey information on risks and benefits to fish consumers by way of fish advisories. Currently, Washington State has ten waterbody specific fish advisories based on PCB levels in tissue and two additional advisories that are likely to be released in 2013. PCBs account for the greatest number of waterbody specific advisories in Washington State and across the country (DOH 2013, EPA 1999).

Table 32 lists those waterbodies and fish species that currently have a fish advisory due to elevated PCB levels.

Table 32: Washington State PCB Fish Advisories

Water Body/Location	Fish Species	Advisory
Green Lake	Common Carp	1 meal per month
Lake Roosevelt	Largescale Suckers	2 meals per month
Lake Washington	Common Carp	Do not eat
	Northern Pikeminnow	Do not eat
	Cutthroat Trout	1 meal per month
	Yellow Perch	1 meal per week
Lower Duwamish River	Resident fish	Do not eat
	Shellfish	Do not eat
	Crab	Do not eat
Lower Columbia- (Bonneville Dam)	Resident fish	Do not eat
Bonneville Dam to McNary Dam	Resident fish	1 meal per week
Okanogan River	Common Carp	1 meal per month
Puget Sound	Chinook	1 meal per week
	Chinook (Blackmouth)	2 meal per month
	English Sole/Flatfish	Varies by location
	Rockfish	Varies by location
Spokane River		
Idaho Border to Upriver Dam	All species	Do not eat
UpRiver Dam to Nine Mile Dam	All species*	1 meal per month
	* Exception: Largescale Suckers	Do not eat
Long Lake (Lake Spokane)	Largescale Suckers, Brown Trout	1 meal per week
	Mountain Whitefish	1 meal per month
Walla Walla River- Lower	Carp	1 meal per month
Lower & Upper	Northern Pikeminnow	Do not eat
Wenatchee River	Mountain Whitefish	Do not eat
Yakima River	Common Carp	1 meal per week
Pending Advisories*		
Mid-Columbia	Lake Whitefish	1 meal per month
	Largescale Suckers	2 meals per month
	Sturgeon	2 meals per month
	Common Carp	1 meal per month
	Walleye	2 meals per month
	Bass	2 meals per month
Snake River	Channel Catfish	2 meals per month
	Common Carp	2 meals per month

* preliminary assessment, meal recommendations may change

Dose Modifications Due to Food Preparation and Cooking

Chemical contaminants are not distributed uniformly in fish. Fatty tissues typically concentrate organic chemicals such as PCBs and dioxins more readily than lean muscle tissue (ATSDR 2004). Muscle tissue can selectively accumulate other contaminants such as mercury (Mieiro et.al, 2009). This preferential concentrating of certain contaminants in one tissue over another has implications for fish testing techniques and consumption of fish.

When DOH provides advice on fish consumption, we calculate meal limits by including potential reductions in chemical concentrations from cleaning and cooking techniques. This calculation is based on efforts from the Great Lakes Fish Advisory Task Force, a three state consortium whose goal was to develop fish advisory protocol. The Task Force reviewed a number of documents related to contaminant reductions through various preparation methods and determined that a 50% reduction factor provided adequate representation for skin-on fillet samples (Great Lakes 1993). Consequently, DOH reduces the calculated exposures by 50% to account for loss of chemical contaminants during preparation and cooking.

Benefits of Fish Consumption

The primary health benefits of eating fish are well documented and relate to the reduction of cardiovascular disease (Yuan et al. 2001, Rodriguez et al. 1996, Hu et al. 2002, Marckmann and Gronbaek 1999, Mozaffarian et al. 2003, Simon et al. 1995, Burr et al. 1989, 1994, Singh et al.1997, and Harrison and Abhyankar 2005) and positive pregnancy outcome (Jorgensen et al. 2001, Olsen et al, 1992, Olsen et al 1995, Olsen and Secher 2002, Carlson et al 1993, 1996, Fadella et al. 1996, San Giovanni et al. 2000, and Helland et al. 2003). Limited data also show a link between fish consumption and a decrease in development of some cancers (SACN 2004, IOM 2007). Additionally, eating fish has been associated with impacts on brain function, including protection against cognitive decline (SACN 2004, IOM 2007).

At present, we know that fish is an excellent protein source that is low in saturated fats, rich in vitamin D, omega-3 fatty acids, and other vitamins and minerals. The health benefits of eating fish are associated with low levels of saturated versus unsaturated fats. Saturated fats are linked with increased cholesterol levels and risk of heart disease while unsaturated fats (e.g., omega-3 polyunsaturated fatty acid) are an essential nutrient. Replacing fish in the diet with other sources of protein may reduce exposure to contaminants but could also result in increased risk for certain diseases (Pan et al., 2012). For example, replacing fish with red meat could increase the risk of cardiovascular disease due to the fact that red meat has higher levels of saturated fat and cholesterol (Law, 2000).

DOH fish advisories work to be protective of human health while acknowledging the benefits of eating fish. This is done by recommending decreased consumption of fish known to have high concentrations of contaminants in favor of fish that are lower in contaminants. DOH supports the

American Heart Association and the U.S. Food and Drug Administration recommendation of consuming at least two servings (12 oz.) of fish per week as part of a healthy diet.

Health benefits of eating fish deserve particular consideration when dealing with groups that consume fish for subsistence. Removal of fish from the diet of subsistence consumers may have serious health, social, cultural and economic consequences. In order to decrease the potential risks of fish consumption, these populations are encouraged to consume a variety of fish species, to fish from locations with low contamination, and to follow recommended preparation and cooking methods.

Recommendation for breast-feeding

DOH recommends that babies be breast fed because breast feeding has many demonstrated health benefits for the developing child and the mother. (DOH website http://www.doh.wa.gov/YouandYourFamily/WIC/BreastfeedingSupport.aspx)

Many investigations have looked for adverse effects associated with PCBs in breast milk and duration of breast feeding. Most studies have shown that prenatal, not postnatal PCB exposure correlates with neurobehavioral effects (Michigan, NC, Patandin et al. 1999, Darvill et al 2000). Breast feeding appears to have a net positive effect on neurobevavioral test performance regardless of PCB concentration of the milk (Jacobson 1990 J Peds).

A Dutch study on PCB and dioxin exposures to children recently found that PCB body burden at 42 months is associated with possible immune deficits. However, when the researches controlled for length of breast feeding, they found that the negative effect of higher postnatal PCB exposure was counteracted by the positive effect of longer duration of nursing in infancy (Weisglas-Kuperus et al., 2000). Using this same cohort, other researcher found neurological and cognitive assessments conducted at 42 months showed that breast-fed children performed better than their formula fed counterparts despite higher prenatal and postnatal to PCBs (Lanting et al 1998, Patandin et al. 1997 and 1999). Follow-up with these children at 6.5 years showed that effects of prenatal exposure to PCBs cognitive and motor abilities were still measureable in the formula fed group and not measurable in the breast-fed group (Vreugdenhil et al., 2002). Analysis of parental and home characteristics suggested that the difference observed at this age was due more to an advantaged home environment than to nutritional benefit of breast-feeding (Vreugdenhil et al., 2002).

Current Regulatory Approaches for PCBs

This chapter describes the existing regulations relevant to PCBs and the activities that generate them at the federal, state, and international levels. It includes a brief summary of many known laws and regulations directly related to management of processes that produce PCBs, the production, use, and disposal of products that contain PCBs, and exposure limits and cleanup levels for PCBs themselves. This chapter is not an exhaustive review of all of the regulations pertinent to PCBs.

In many instances, federal laws and regulations delegate the authority for implementing these laws and regulations to state or Tribal governments. In some cases, states adopt laws and promulgate regulations that are more stringent than their federal partners.

Federal Laws & Regulations

Toxic Substances Control Act

15 USC 2601 et seq., Toxic Substances Control Act

The Toxic Substances Control Act of 1976 (15 USC 2601 et seq.) gives EPA the authority to regulate new and existing substances. TSCA gives EPA the authority to require reporting, record-keeping and testing requirements, and restrictions relating to chemical substances and/or mixtures. Certain substances are generally excluded from TSCA, including, among others, food, drugs, cosmetics, and pesticides.

TSCA is the primary federal regulatory instrument pertinent to PCBs in the United States. PCBs are addressed by Section 761 of TSCA. TSCA became law on Oct. 11, 1976 with an effective date of one year later (1977) that "no person may manufacture, process, or distribute in commerce or use any polychlorinated biphenyl in any manner other than in a totally enclosed manner."

Table 33 summarizes several subparts of TSCA and their contents (exerpted from Neuberger)

Table 33: Subparts of TSCA

Subpart A	General regulations governing PCBs
Subpart B	Manufacturing, processing, distribution in commerce and use of PCBs and PCB items, including: • Totally enclosed uses (e.g. transformers, capacitors) • Non-totally enclosed uses (including requirements for servicing PCB-containing equipment) • PCB solids

	• Other uses
Subpart C	Marking of PCBs and PCB items
Subpart D	Storage and disposal, including: • PCB disposal methods • Remediation waste cleanups • PCB household waste storage and disposal • PCB decontamination standards and procedures • Storage for disposal
Subpart E	Manufacturing, processing, and distribution in commerce exemptions, including: • Research and development for disposal technologies • Analytical reference samples • Recycled PCBs, defined as those that appear in the processing of paper products or asphalt roofing materials from PCB-contaminated raw materials
Subpart F	Transboundary shipments of PCBs for disposal
Subpart G	PCB spill cleanup policy
Subpart J	General records and reports

Continued use and disposal of existing PCBs is governed by a framework of controls driven by the form the PCBs take (liquid form, non-liquid form, or multi-phasic, meaning a combination of liquid and non-liquid forms) and the amount of PCBs in each form. In general (with exceptions), PCBs in concentrations of less than 50 ppm in most media are not considered by the regulations to pose an unreasonable risk to human health or the environment and are excluded from regulation (Chary and Neuberger).

We are not detailing or even summarizing all of TSCA that pertains to PCBs. Below are some important requirements under TSCA:

- Prohibition of manufacture, sale, and distribution, with exceptions.
- Use of PCBs limited to certain "totally enclosed" uses, such as transformers and capacitors.
- By December 1998, all known transformers containing PCBs >500 ppm were required to be registered with EPA.
- Safe disposal.
- Small nonleaking PCB capacitors may be disposed of as municipal solid waste.
- Labels identifying electrical equipment containing over 500 ppm PCBs.
- PCB transformers that contain more than 60,000 ppm PCBs must be inspected for leaks quarterly, and transformers with less than 60,000 ppm PCBs and those with appropriate secondary containment must be inspected for leaks at least annually.

- To prevent PCB fires, high-voltage network PCB-containing transformers must be removed or reclassified and enhanced electrical protection must be added on many types of PCB transformers in, or within 30 meters of, commercial buildings.[12]

TSCA Rules

Under TSCA EPA has promulgated 29 rules for the regulation of PCBs. A list of rules, with the associated notices, drafts, etc. can be found on the EPA website at http://www.epa.gov/wastes/hazard/tsd/pcbs/pubs/laws.htm. We are not going to provide details of each rule here. In general, each rule addresses a specific portion of managing PCBs, such as labeling and spills. Below is some information on two specific regualtions.

1. 44 FR 31514 PCBs; Manufacturing, Processing, Distribution in Commerce and Use Bans. This 1979 rule implemented the ban on PCBs and established 50 ppm PCBs as the general regulatory limit.

2. 49 FR 28172 Polychlorinated Biphenyls (PCBs) Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions; Exclusions, Exemptions, and Use Authorizations

EPA promulgated a rule in 1984 for inadvertent generation of PCBs that are not in closed or controlled manufacturing processes (49 FR 28172). EPA found the societal benefit of these products and the cost of not producing PCBs outweighed the risks to human health and the environment from these sources of PCBs. The rule was based on a consensus proposal from the Environmental Defense Fund, Natural Resources Defense Council, and Chemical Manufacturers Association (now known as the American Chemistry Council). It requires that the concentration of inadvertently generated PCBs in products, including recycled paper, must have an annual average of < 25 ppm, with a maximum of 50 ppm. Detergent bars are treated differently as they are consumer products with a high potential for exposure, and are limited to 5ppm (soap and deodorant are regulated by the FDA).

There were several additional criteria in the rule:

- Releases to ambient air must be less than 10ppm.
- Discharges to water must be less than 0.1ppm, except from recyclable paper the limit is 3 ppb total Aroclors.
- All wastes must be disposed of properly. Process wastes with PCB levels > 50 ppm must be disposed of in accordance with TSCA.
- The concentration of monochlorinated biphenyls is discounted by a factor of 50 and dichlorinated biphenyls are discounted by a factor of 5.
- Certification, reporting, and records maintenance.

The numerical limits in the law were set at the Limits of Quantification (LOQs) at the time.

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[12] Panero, M., Boheme, S., and Muñoz, G. Pollution Prevention and Management Strategies for Polychlorinated Biphenyls in the New York/New Jersey Harbor. February 2005. New York Academy of Sciences, New York, NY. Available at: http://www.nyas.org/WhatWeDo/Harbor.aspx

The rule clarifies some overlap between TSCA with FIFRA and FFDCA. If a chemical is solely manufactured for a use that is regulated by FIFRA or FFDCA, then that substance is not regulated under TSCA. If only some uses are regulated under FIFRA, then the chemical is regulated under TSCA until it becomes part of an identified pesticide product. However, chemicals used in FDA-regulated products under FFDCA (like a food, food additive, drug, cosmetic, or medical device) are excluded from TSCA jurisdiction.

Water Regulations

33 USC 1251 et seq., The Clean Water Act (CWA)

EPA has established water quality criteria for certain compounds that define levels to protect human health and aquatic life. The Clean Water Act and its amendments prohibit discharging pollutants from a point source without a National Pollutant Discharge Elimination System (NPDES) permit. These permits include conditions to protect water quality. The EPA and authorized states to issue and monitor compliance with these permits. The Clean Water Act also directs EPA to establish technology-based standards, known as Best Available Technology (BAT) requirements to prevent discharges of harmful amounts of pollutants.

Stormwater from certain industries and municipalities is also considered a point source of pollution that requires NPDES permitting[13]. PCBs from various sources that are deposited on land and washed into storm drains would be regulated under these stormwater permits. EPA's stormwater regulations establish two phases for the stormwater permit program:

- Phase I stormwater permits, which cover discharges from certain industries, construction sites involving more five or more acres, and municipalities with a population of more than 100,000.
- Phase II stormwater permits, which cover all municipalities located in urbanized areas and to construction sites between one and five acres. The EPA rule also requires an evaluation of cities outside of urbanized areas that have a population over 10,000, to determine if a permit is necessary for some or all of these cities.

National Recommended Water Quality Critera[14]

PCBs are a Priority Pollutant under the CWA. EPA has national recommended water quality criteria for the protection of aquatic life and human health in surface water for about 150 pollutants. These criteria are published pursuant to Section 304(a) of the Clean Water Act and provide guidance to states. For aquatic health the chronic freshwater criterion is 0.014 ug/L and

[13] Department of Ecology. How is Stormwater Regulated? Available at: http://www.ecy.wa.gov/programs/wq/stormwater/municipal/howregulated.html

[14] US EPA. National Recommended Water Quality Criteria. Available at: http://water.epa.gov/scitech/swguidance/standards/current/index.cfm (accessed 9 June 2011).

0.03 ug/L for saltwater. For human health the criteria are 0.000064 ug/L both for the consumption of water and organism and for the consumption of organism only.

National Toxics Rule (40 CFR 131.36).[15]

The National Toxics Rule promulagated chemical-specific numerical criteria for priority toxic pollutants for 14 states to bring them into compliance with requirements of section 303(c)(2)(B) of the CWA. This rule became effective in 1993. The criteria for PCBs for both freshwater and marine water is 0.00017 ug/L, which has a fish tissue equivalent of 5.304 ug/kg.

42 USC 300f et seq., Safe Drinking Water Act (SDWA)

The Safe Drinking Water Act specifies water quality standards for drinking water. The National Primary Drinking Water regulations under the SDWA apply to public water systems with at least 15 service connections or more than 25 individuals for more than 60 days per year.

The SDWA sets two drinking water standards. The Maximum Contaminant Level Goal (MCLG) is a non-enforceable health goal. The Maximum Contaminant Level (MCL) is the legally enforceable standard. Water systems must reduce levels of the contaminant as close to the MCLG as feasible, considering technology, treatment techniques, and costs. For PCBs the MCLG is zero and the MCL is 0.0005mg/L (ppm)[16]

Air Regulations

42 USC 7401, Clean Air Act and Amendments

PCBs are regulated under Section 112 of the Clean Air Act as Hazardous Air Pollutants (HAPs).

Regulation under Section 112 of the Clean Air Act requires major sources of HAPs to meet standards based on Maximum Achievable Control Technology (MACT). These standards must require the maximum degree of emission reduction that the EPA determines to be achievable by each particular source category. Different criteria for MACT apply for new and existing sources. For existing major sources, MACT is defined as the technology used to control emissions at the top 12% of facilities within the same source category. Eight to nine years after MACT is implemented, EPA is required to conduct a residual risk analysis. If the "residual risk" for a source category does not protect public health with "an ample margin of safety," the EPA must promulgate health-based standards for that source category to further reduce HAP emissions.

PCBs are one of several substances listed in Section 112(c)(6) of the Clean Air Act, which requires EPA to "list categories and subcategories of sources assuring that sources accounting for

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[15]US EPA. Water Quality Standards; Establishment of Numeric Criteria for Priority Toxic Pollutants; States' Compliances. 57 FR 60848. Available at: http://water.epa.gov/lawsregs/rulesregs/ntr/index.cfm (accessed 21 Oct 2013).

[16] US EPA. List of Contaminants & their MCLs. Available at: http://water.epa.gov/drink/contaminants/index.cfm#List (accessed 9 June 2011).

not less than 90 per centum of the aggregate emissions of each such pollutant are subject to standards." EPA published this listing in a Federal Register notice in June 1997.[17] Various forms of waste incineration were identified as the primary industrial source categories emitting PCBs.

Waste, Hazardous Substance & Cleanup Regulations

42 USC 6901 et seq., Resource Conservation and Recovery Act (RCRA)

Under the authority of the Resource Conservation and Recovery Act of 1976, EPA implements regulations pertaining to solid waste, hazardous waste and underground storage tanks (40 CFR parts 239-299).

Hazardous wastes are managed under RCRA from their point of generation to their proper disposal or treatment. There are three means under RCRA of identifying if a waste is hazardous: (1) if the waste is specifically listed as hazardous, (2) if it exhibits hazardous characteristics, as determined by a Toxicity Characteristic Leaching Procedure (TCLP) test or 3) exhibits the characteristics of ignitability, corrosivity or reactivity.

Wastes are given waste codes based on their sources or specific properties. D codes are for characteristic wastes. P and U waste codes are assigned to discarded chemical products. F codes are for non-specific and K codes are for specific industrial sources.

Standards for the Management of Used Oil (40 CFR Part 279)[18] Includes management standards for generators, transporters, processors, burners, and marketers of used oil containing PCBs at less than 50 ppm. Used oil containing more than 50 ppm is regulated under TSCA (40 CFR part 761).

42 USC Part 103, Comprehensive Environmental Response, Compensation and Liability Act (CERCLA)

CERCLA, passed in 1980, is the primary federal authority used to regulate and cleanup historic hazardous waste sites. The statute and implementing regulations establish procedures for the long-term remediation of such sites, but also provides authority to clean up hazardous waste sites in need of immediate action. The law has subsequently been amended, by the Superfund Amendments and Reauthorization Act of 1986 (SARA), and the Small Business Liability Relief and Brownfields Revitalization Act of 2002.

[17] Notice of draft source category listing for section 112(d)(2) rulemaking pursuant section 112(c)(6) requirements. 62 FR 119 (20 June 1997). p. 33625 - 33638.

[18] US EPA. Standards for the Management of Used Oil. 40 CFR Part 279. Available at: http://www.access.gpo.gov/nara/cfr/waisidx_07/40cfr279_07.html (accessed 10 June 2011).

Under CERCLA Section 103, releases of hazardous substances are required to be reported to the National Response Center if they exceed the Reportable Quantity (RQ) for that substance, which is 1 pound for PCBs.[19]

42 USC Part 116, Emergency Planning and Community Right-to-Know Act (EPCRA)

EPCRA, or SARA Title III, is intended to protect public health and the environment from hazards posed by toxic chemicals by providing information about the presence of toxic chemicals in communities. The Act, passed in 1986, creates the annual hazardous chemical inventory as well as the toxics release inventory (TRI).

Under Section 302 of EPCRA, facilities that manufacture, process or use chemicals on the list of Extremely Hazardous Substances (EHSs) must report the presence of those chemicals the presence of those chemicals above a certain quantity, known as the Threshold Planning Quantity (TPQ).

Section 313 of EPCRA establishes the Toxics Release Inventory (TRI). Under the TRI, the release or waste management of toxic chemicals by certain industries must be reported if the quantity of a chemical that is manufactured, processed, or otherwise used during the calendar year exceeds the reporting threshold. For most TRI chemicals, the thresholds are 25,000 pounds manufactured or 10,000 pounds otherwise used.[20] The reporting threshold for PBTs is lower and is 10 lbs for PCBs.

Worker & Product Safety Regulations

84 USC 1590 et seq., Occupational Safety and Health Act (OSHA)

The Occupational Safety and Health Act allows the Occupational Safety and Health Administration (OSHA) to set protective regulatory limits on the amount or concentration of a substance in the air in workplaces. These limits, called Permissible Exposure Limits (PELs) are based on an average exposure over an 8 hour workday, or a Time-Weighted Average (TWA).[21] OSHAs PEL is 1,000 $\mu g/m^3$ for PCBs containing 42% chlorine (CAS 53469-21-9) and 500 $\mu g/m^3$ for compounds containing 54% chlorine (CAS 11097-69-1). The PELs include "skin" to refer to the contribution to overall exposure through skin. These are based on the prevention of livery injury in exposed workers.

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[19] US EPA. List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act. EPA 550-B-01-003. October 2012. Available at: http://www.epa.gov/emergencies/tools.htm#lol (accessed 21 October 2013).

[20] US EPA. List of Lists: Consolidated List of Chemicals Subject to the Emergency Planning and Community Right-To-Know Act (EPCRA) and Section 112(r) of the Clean Air Act. EPA 550-B-01-003. October 2012. Available at: http://www.epa.gov/emergencies/tools.htm#lol (accessed 21 October 2013).

[21] Occupational Safety and Health Administration. Permissible Exposure Limits (PELs). Available at: https://www.osha.gov/dsg/topics/pel/ (accessed 21 October 2013).

The National Institute for Occupational Safety and Health (NIOSH) recommends a 10-hour TWA of 1 µg/m^3 based on the minimum reliable detectable concentration and the potential carcinogenicity of PCBs.[22] The NIOSH recommended exposre limit (REL) was based on reproductive effects in animal models, carcinogenic effects, and prevention of liver injury. NIOSH also recommends that all workplace exposures be reduced to the lowest feasible level.

Washington State Laws and Regulations

Water Regulations

Chapter 90.48 RCW Water Pollution Control

Chapter 173-200 WAC Water quality standards for groundwaters of the state of Washington.
This regulation is intended to protect current and future beneficial uses of groundwater from deleterious effects, prevent degradation of waters of outstanding value, and actively maintain the higher quality of waters that exceed water quality criteria.

Chapter 173-201A WAC Water quality standards for surface waters of the state of Washington.
This regulation institutes narrative and numeric criteria for surface water quality, an anti-degradation policy, and use-based protection measures.

Chapter 70.142 RCW Chemical Contaminants and Water Quality

This law allows the State Board of Health to establish standards for allowable concentrations of chemical contaminants in public water supplies.

Chapter 246-290 WAC Water quality standards for groundwaters of the state of Washington
This regulation establishes regulatory requirements applicable to public drinking water supplies.

Multiple Statutes — Chapters 90.48, 70.105D, 90.70, 90.52, 90.54 and 43.21 RCW

Chapter 173-204 WAC, Sediment Management Standards
Enacted in 1991, this chapter establishes marine, low salinity and freshwater surface sediment management standards. The purpose of this chapter is to reduce health threats to humans and biological resources resulting from surface sediment contamination.[23]

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[22] Polychlorinated Biphenyls (PCBs). Current Intelligence Bulletin 45 (1986) http://www.cdc.gov/niosh/docs/86-111/ (accessed 21 October 2013)
[23] WAC 173-204-320. Table 1, Marine Sediment Quality Standards. Available at: http://apps.leg.wa.gov/wac/default.aspx?cite=173-204-320 (accessed 10 June 2011).

Air Regulations

Chapter 70.94 RCW Washington Clean Air Act

The Washington Clean Air Act authorizes the Department of Ecology to develop and implement regulations that are needed control air pollution.

Chapter 173-460 WAC Controls for new sources of toxic air pollutants

Under this chapter, Ecology reviews new sources of toxic air pollutants and establishes emission control requirements that are needed to prevent air pollution that may impact human health and safety. This chapter, enacted in 1991, requires new sources to implement best available control technology for toxics (tBACT). The owner or operator of a new toxic air pollutant source must also conduct an acceptable source impact level (ASIL) analysis for toxic air pollutants. When performing these assessments, the owner/operator must quantify the amount of toxic air pollutant likely to be emitted from the new source and estimate ambient air concentrations that might result from those emissions. Ambient air concentrations are estimated using air quality models. The model air concentrations are then compared to regulatory screening values (ASIL). If the modeled concentration exceeds the ASIL screening levels, the owner/operator must perform a comprehensive review using a more sophisticated model and, if necessary, apply additional emission controls. Violators may be subject to enforcement actions, civil penalties and/or criminal charges such as gross misdemeanor. Twelve PCB congeners and general PCBs (CAS 1336-36-3) are regulated as toxic air pollutants (TAPs).[24]

Waste, Hazardous Substance & Cleanup Regulations

Multiple Statutes - Chapter 70.105 RCW and parts of chapters 70.105A, 70.105D and 15.54 RCW

Chapter 173-303 WAC, Dangerous Waste Regulations

These regulations meet the requirements of the Federal Resource Conservation and Recovery Act (RCRA) and the Department of Ecology is authorized by the US EPA to implement RCRA within the state. Therefore, all the requirements identified under RCRA are also part of the state's dangerous waste regulations. In addition, this chapter also contains specific state-only dangerous waste requirements for any waste generated or disposed of within the state. The dangerous waste regulations require a generator of dangerous waste to designate that waste according to the regulations and follow the associated requirements for waste of that designation.

[24] WAC 173-460-450. Table of ASIL, SQER and de minimis emission values. Available at: http://apps.leg.wa.gov/WAC/default.aspx?cite=173-460-150 (accessed 10 June 2011).

Washington State has specific requirements that pertain to toxicity and persistent criteria. Halogenated organic compounds like PCBs are considered persistent in the dangerous waste regulations.

WAC 173-303-100(5) requires waste to be evaluated for mammalian and aquatic toxicity and WAC 173-303-100(5)(b)(i) provides a process to designate a specific waste stream based upon the toxicity of the individual components. In this evaluation, toxicity must be considered with other waste constituents to determine if the waste stream designates as a state-only toxic waste and assigned the waste codes of WT02 as dangerous waste or WT01 as EHW (extremely hazardous waste).

In Washington Staet, PCB waste may be regulated as a state criteria dangerous waste or as a state listed dangerous waste. The Washington dangerous waste regulations separate wastes into four categories:

- Characteristic wastes.
- Criteria wastes.
- Discarded chemical products.
- Non-specific and specific industrial sources.

Wastes are given waste codes based on their sources or specific properties as discussed in the Federal Regulations section on RCRA. W codes are for state-only wastes.

PCBs as a state criteria dangerous waste

Since PCBs meet the definition of Halogenated Organic Compound (WAC 173-303-040), wastes containing PCBs (other than state listed PCB wastes discussed below) must be evaluated for state persistence. This requirement has been in place since early adoption of the State's Dangerous Waste Regulations in 1982. At 100ppm PCB, a waste would be considered a persistent dangerous waste (waste code WP02). A few examples of PCB persistent waste include: caulking's, tars and rubber stripping at the airport runways. If the PCB concentration exceeds 10,000ppm (waste code WP01), the waste is recognized as an extremely hazardous waste pulling on additional requirements and/or prohibits on the management of that waste.

PCBs as a state listed dangerous wastes

To address the management of the most problematic PCB wastes, which were the liquid PCB of transformers, bushings and capacitors, RCW 70.105.105 gave the authority to Ecology to regulate PCBs as a dangerous waste. In 1985, Ecology amended its Dangerous Waste Regulations to include certain PCB wastes (waste code WPCB). This is a source specific group of waste that only applies to discarded transformers, capacitors or bushings containing 2ppm PCB or greater (except when drained of all free flowing liquid) and to the following wastes generated from the salvaging, rebuilding, or discarding of transformers, capacitors or bushing at 2ppm PCB or greater: cooling and insulation fluids, cores, and core papers.

Exclusions

1) -071(3)(k). PCB exclusion. One may manage a state only PCB waste under specific TSCA regulations instead of the state Dangerous Waste regulations. The waste would become excluded from the state Dangerous Waste regulationss. Often, listed-WPCB dangerous wastes are managed under this exclusion.

2) -073 "Special waste exclusion". If the waste meets the definition of special waste (WAC 173-303-040), then some listed WPCB wastes and some state only persistent criteria waste (due to PCB) can be managed this way.

Chapter 70.95I RCW Used oil recycling

Used oil is conditionally regulated under the dangerous waste regulations as long as 1) it is not contaminated with chlorinated solvents or PCBs and 2) it is managed appropriately. If used oil is not contaminated, it may be recycled or burned for energy recovery. Used oil with 2 ppm or greater PCBs is prohibited from being managed as used oil under the Dangerous Wastes used oil regulations when burned for energy recovery. WAC 173-303-515 contains management standards for used oil.

This statute requires local governments to include an element in their hazardous waste plans enumerating how they will collect used oil. It also requires used oil recycling containers and educational information about used oil to be provided at any business that sells above 1,000 gallons of lubricating oil to consumers (500 gallons in a city with an approved used oil recycling element in their hazardous waste plan).

Chapter 70.105D RCW Hazardous Waste Cleanup – Model Toxics Control Act

Chapter 173-340 WAC, Model Toxics Control Act – Cleanup

Chapter 70.105D RCW establishes the framework and authority for the development of a program dealing with the cleanup of sites contaminated with toxic chemicals. The MTCA Cleanup Regulation, issued in 1991, establishes procedures and standards for the identification, investigation and cleanup of facilities contaminated with hazardous wastes.

MTCA provides several methods for setting cleanup standards. Under MTCA Method A, pre-calculated protective cleanup levels are available in tables within the regulation for use at relatively simple sites.

Method B is the universal method for determining cleanup levels for all media at all sites. A target cancer risk level of one in one million (10^{-6}) is used when calculating cleanup levels under Method B. Toxicity equivalency factor (TEF) methodology (Van Den Berg et al. 2006) may also

be used to evaluate the toxicity of PCBs, where the mixture is considered a single hazardous substance.[25]

Method C cleanup levels are established when cleanup levels established under Method A or B may be impossible to achieve or may cause greater environmental harm.

Chapter 173-360 WAC, Underground Storage Tank Regulations

The Department of Ecology implements Chapter 90.76 RCW, Underground Storage Tanks, in order to protect human health and the environment from leaking underground storage tanks containing petroleum and other regulated substances. No underground storage tank systems, within the parameters of this chapter's scope, may operate without a valid permit. This chapter sets forth performance standards for underground storage tanks. Tanks must be monitored and owners and operators are required to comply fully with testing and inspection. Releases into the surrounding environment must be immediately reported to Ecology and appropriate cleanup and containment measures must be taken. Under most circumstances, MTCA cleanup standards apply to the remediation of releases from leaking underground storage tanks. This chapter was adopted in 1990 and violators face fines of up to $5,000 dollars per day per violation.

Worker & Product Safety Regulations

Chapter 49.17 RCW Washington Industrial Safety and Health Act

Chapter 296-841 WAC Airborne Contaminants

This chapter specifies Permissible Exposure Limits (PELs) of 1,000 µg/m^3 for PCBs containing 42% chlorine (CAS 53469-21-9) and 500 µg/m^3 for compounds containing 54% chlorine (CAS 11097-69-1) that mirror the federal OSHA requirements (see Federal Regulations).

They also specify Short-Term Exposure Limits (STEL) of 3,000 µg/m^3 for PCBs containing 42% chlorine (CAS 53469-21-9) and 1,500 µg/m^3 for compounds containing 54% chlorine (CAS 11097-69-1). STELs refer to 15 minute exposure periods.

Taxes

Chapter 82.21 RCW Hazardous substance tax – model toxics control act

Chapter 458-20-252 WAC Hazardous substance tax and petroleum product tax

PCBs are taxed under the Hazardous Substance Tax.

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[25] Department of Ecology. Evaluating the Toxicity and Assessing the Carcinogenic Risk of Environmental Mixtures Using Toxicity Equivalency Factors. Available at: https://fortress.wa.gov/ecy/clarc/FocusSheets/tef.pdf (accessed 16 June 2011).

This law places a tax on the first possession of hazardous substances in Washington. The Department of Ecology determines which substances are subject to the tax. The tax applies to petroleum products, pesticides, and certain chemicals. There are currently over 8,000 different hazardous substances identified as being subject to the tax. The tax rate is .007 of the wholesale value of the product. Funds are distributed to the Department of Ecology to help clean up, manage and prevent solid and hazardous waste in the state of Washington.[26] The tax does not apply to components or contaminants, such as inadvertently generated PCBs in other products.

The tax applies to

- Petroleum products.
- Substances designated as hazardous under the federal Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA – see Federal Regulations).
- Any pesticide product required to be registered under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA – see Federal Regulations).
- Other substances or categories of substances designated by Ecology.

Select Regulations in Other US Jurisdictions

Maine

http://www.mainelegislature.org/legis/statutes/38/title38sec419-B.html

This law requires public utilities to remove transformers with more than 50 ppm PCBs. There are earlier deadlines for transformers within 100 feet surface water, elementary school or secondary school.

Select International Regulations

Most countries have prohibited the commercial manufacturing of PCBs.

Stockholm Convention[27]

The Stockholm Convention on Persistent Organic Pollutants is a global treaty that aims to protect human health and the environment from the effects of persistent organic pollutants. The Convention has a range of control measures to reduce and, where feasible, eliminate the release of POPs. The Convention also aims to ensure the sound management of stockpiles and wastes that contain POPs.

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[26] Washington State Department of Revenue. Hazardous substance tax. Available at: http://dor.wa.gov/content/findtaxesandrates/othertaxes/tax_hazard.aspx

[27] http://chm.pops.int/Home/tabid/2121/mctl/ViewDetails/EventModID/871/EventID/407/xmid/6921/Default.aspx

The Convention was signed in 2001 and entered into force in 2004. The US is a signatory, but has not ratified the Convention, so is not a Party to it.

PCBs are one of the 12 initial POPs under the Stockholm Convention. The parties to the Convention are required to eliminate the use of PCBs in existing equipment by 2025 and ensure environmentally sound waste management of them by 2028. Each country is expected to develop inventories and identify contaminated sites. To help stakeholders achieve the goals in the Stockholm Convention they created the PCB Elimination Network (PEN).

Canada

PCBs were never manufactured in Canada and most PCBs used in Canada were imported from the US. Like the US, Canada banned the import, manufacture, and sale of PCBs in 1977 and allowed PCB equipment to be used until the end of its service life.

The release of PCBs to the environment was made illegal in 1985.

The Canadian Environmental Protection Act (CEPA) covers PCB Regulations.[28] Many of the regulations are similar to TSCA, such as a general limit of 50 ppm. One major difference is the Canadian regulations set deadlines for the phase-out of PCBs in use:

- Dec. 31, 2009 for equipment containing more than 500 ppm PCBs
- Dec. 31, 2009 for equipment containing 50-500 ppm PCBs within 100 meters of a drinking water plant, food or feed processing plant, school, hospital, or care center
- Dec. 31, 2025 for other equipment containing 50-500 ppm PCB
- Dec. 31, 2025 for light ballasts and pole-top electrical transformers

[28] SOR/2008-273 available at http://www.ec.gc.ca/bpc-pcb/default.asp?lang=En&n=663E7488-1 (accessed 21 October 2013).

Economic analyses

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Appendices

Appendix A: List of 209 PCB Congeners (EPA, 2003)

CASRN	Congener Number	IUPAC Name
1336-36-3		Polychlorinated biphenyl (PCB)
2051-60-7	1	2-Chlorobiphenyl
2051-61-8	2	3-Chlorobiphenyl
2051-62-9	3	4-Chlorobiphenyl
13029-08-8	4	2,2'-Dichlorobiphenyl
16605-91-7	5	2,3-Dichlorobiphenyl
25569-80-6	6	2,3'-Dichlorobiphenyl
33284-50-3	7	2,4-Dichlorobiphenyl
34883-43-7	8	2,4'-Dichlorobiphenyl
34883-39-1	9	2,5-Dichlorobiphenyl
33146-45-1	10	2,6-Dichlorobiphenyl
2050-67-1	11	3,3'-Dichlorobiphenyl
2974-92-7	12	3,4-Dichlorobiphenyl
2974-90-5	13	3,4'-Dichlorobiphenyl
34883-41-5	14	3,5-Dichlorobiphenyl
2050-68-2	15	4,4'-Dichlorobiphenyl
38444-78-9	16	2,2',3-Trichlorobiphenyl
37680-66-3	17	2,2',4-Trichlorobiphenyl
37680-65-2	18	2,2',5-Trichlorobiphenyl
38444-73-4	19	2,2',6-Trichlorobiphenyl
38444-84-7	20	2,3,3'-Trichlorobiphenyl
55702-46-0	21	2,3,4-Trichlorobiphenyl
38444-85-8	22	2,3,4'-Trichlorobiphenyl
55720-44-0	23	2,3,5-Trichlorobiphenyl
55702-45-9	24	2,3,6-Trichlorobiphenyl
55712-37-3	25	2,3',4-Trichlorobiphenyl
38444-81-4	26	2,3',5-Trichlorobiphenyl
38444-76-7	27	2,3',6-Trichlorobiphenyl
7012-37-5	28	2,4,4'-Trichlorobiphenyl
15862-07-4	29	2,4,5-Trichlorobiphenyl
35693-92-6	30	2,4,6-Trichlorobiphenyl
16606-02-3	31	2,4',5-Trichlorobiphenyl
38444-77-8	32	2,4',6-Trichlorobiphenyl
38444-86-9	33	2,3',4'-Trichlorobiphenyl
37680-68-5	34	2,3',5'-Trichlorobiphenyl
37680-69-6	35	3,3',4-Trichlorobiphenyl
38444-87-0	36	3,3',5-Trichlorobiphenyl
38444-90-5	37	3,4,4'-Trichlorobiphenyl
53555-66-1	38	3,4,5-Trichlorobiphenyl
38444-88-1	39	3,4',5-Trichlorobiphenyl
38444-93-8	40	2,2',3,3'-Tetrachlorobiphenyl
52663-59-9	41	2,2',3,4-Tetrachlorobiphenyl
36559-22-5	42	2,2',3,4'-Tetrachlorobiphenyl

CASRN	Congener Number	IUPAC Name
70362-46-8	43	2,2',3,5-Tetrachlorobiphenyl
41464-39-5	44	2,2',3,5'-Tetrachlorobiphenyl
70362-45-7	45	2,2',3,6-Tetrachlorobiphenyl
41464-47-5	46	2,2',3,6'-Tetrachlorobiphenyl
2437-79-8	47	2,2',4,4'-Tetrachlorobiphenyl
70362-47-9	48	2,2',4,5-Tetrachlorobiphenyl
41464-40-8	49	2,2',4,5'-Tetrachlorobiphenyl
62796-65-0	50	2,2',4,6-Tetrachlorobiphenyl
68194-04-7	51	2,2',4,6'-Tetrachlorobiphenyl
35693-99-3	52	2,2',5,5'-Tetrachlorobiphenyl
41464-41-9	53	2,2',5,6'-Tetrachlorobiphenyl
15968-05-5	54	2,2',6,6'-Tetrachlorobiphenyl
74338-24-2	55	2,3,3',4-Tetrachlorobiphenyl
41464-43-1	56	2,3,3',4'-Tetrachlorobiphenyl
70424-67-8	57	2,3,3',5-Tetrachlorobiphenyl
41464-49-7	58	2,3,3',5'-Tetrachlorobiphenyl
74472-33-6	59	2,3,3',6-Tetrachlorobiphenyl
33025-41-1	60	2,3,4,4'-Tetrachlorobiphenyl
33284-53-6	61	2,3,4,5-Tetrachlorobiphenyl
54230-22-7	62	2,3,4,6-Tetrachlorobiphenyl
74472-34-7	63	2,3,4',5-Tetrachlorobiphenyl
52663-58-8	64	2,3,4',6-Tetrachlorobiphenyl
32284-54-7	65	2,3,5,6-Tetrachlorobiphenyl
32598-10-0	66	2,3',4,4'-Tetrachlorobiphenyl
73575-53-8	67	2,3',4,5-Tetrachlorobiphenyl
73575-52-7	68	2,3',4,5'-Tetrachlorobiphenyl
60233-24-1	69	2,3',4,6-Tetrachlorobiphenyl
32598-11-1	70	2,3',4',5-Tetrachlorobiphenyl
41464-46-4	71	2,3',4',6-Tetrachlorobiphenyl
41464-42-0	72	2,3',5,5'-Tetrachlorobiphenyl
74338-23-1	73	2,3',5',6-Tetrachlorobiphenyl
32690-93-0	74	2,4,4',5-Tetrachlorobiphenyl
32598-12-2	75	2,4,4',6-Tetrachlorobiphenyl
70362-48-0	76	2,3',4',5'-Tetrachlorobiphenyl
32598-13-3	77	3,3',4,4'-Tetrachlorobiphenyl
70362-49-1	78	3,3',4,5-Tetrachlorobiphenyl
41464-48-6	79	3,3',4,5'-Tetrachlorobiphenyl
33284-52-5	80	3,3',5,5'-Tetrachlorobiphenyl
70362-50-4	81	3,4,4',5-Tetrachlorobiphenyl
52663-62-4	82	2,2',3,3',4-Pentachlorobiphenyl
60145-20-2	83	2,2',3,3',5-Pentachlorobiphenyl
52663-60-2	84	2,2',3,3',6-Pentachlorobiphenyl
65510-45-4	85	2,2',3,4,4'-Pentachlorobiphenyl
55312-69-1	86	2,2',3,4,5-Pentachlorobiphenyl
38380-02-8	87	2,2',3,4,5'-Pentachlorobiphenyl
55215-17-3	88	2,2',3,4,6-Pentachlorobiphenyl
73575-57-2	89	2,2',3,4,6'-Pentachlorobiphenyl
68194-07-0	90	2,2',3,4',5-Pentachlorobiphenyl
68194-05-8	91	2,2',3,4',6-Pentachlorobiphenyl
52663-61-3	92	2,2',3,5,5'-Pentachlorobiphenyl
73575-56-1	93	2,2',3,5,6-Pentachlorobiphenyl

CASRN	Congener Number	IUPAC Name
73575-55-0	94	2,2',3,5,6'-Pentachlorobiphenyl
38379-99-6	95	2,2',3,5',6-Pentachlorobiphenyl
73575-54-9	96	2,2',3,6,6'-Pentachlorobiphenyl
41464-51-1	97	2,2',3,4',5'-Pentachlorobiphenyl
60233-25-2	98	2,2',3,4',6'-Pentachlorobiphenyl
38380-01-7	99	2,2',4,4',5-Pentachlorobiphenyl
39485-83-1	100	2,2',4,4',6-Pentachlorobiphenyl
37680-73-2	101	2,2',4,5,5'-Pentachlorobiphenyl
68194-06-9	102	2,2',4,5,6'-Pentachlorobiphenyl
60145-21-3	103	2,2',4,5',6-Pentachlorobiphenyl
56558-16-8	104	2,2',4,6,6'-Pentachlorobiphenyl
32598-14-4	105	2,3,3',4,4'-Pentachlorobiphenyl
70424-69-0	106	2,3,3',4,5-Pentachlorobiphenyl
70424-68-9	107	2,3,3',4',5-Pentachlorobiphenyl
70362-41-3	108	2,3,3',4,5'-Pentachlorobiphenyl
74472-35-8	109	2,3,3',4,6-Pentachlorobiphenyl
38380-03-9	110	2,3,3',4',6-Pentachlorobiphenyl
39635-32-0	111	2,3,3',5,5'-Pentachlorobiphenyl
74472-36-9	112	2,3,3',5,6-Pentachlorobiphenyl
68194-10-5	113	2,3,3',5',6-Pentachlorobiphenyl
74472-37-0	114	2,3,4,4',5-Pentachlorobiphenyl
74472-38-1	115	2,3,4,4',6-Pentachlorobiphenyl
18259-05-7	116	2,3,4,5,6-Pentachlorobiphenyl
68194-11-6	117	2,3,4',5,6-Pentachlorobiphenyl
31508-00-6	118	2,3',4,4',5-Pentachlorobiphenyl
56558-17-9	119	2,3',4,4',6-Pentachlorobiphenyl
68194-12-7	120	2,3',4,5,5'-Pentachlorobiphenyl
56558-18-0	121	2,3',4,5',6-Pentachlorobiphenyl
76842-07-4	122	2,3,3',4',5'-Pentachlorobiphenyl
65510-44-3	123	2,3',4,4',5'-Pentachlorobiphenyl
70424-70-3	124	2,3',4',5,5'-Pentachlorobiphenyl
74472-39-2	125	2,3',4',5',6-Pentachlorobiphenyl
57465-28-8	126	3,3',4,4',5-Pentachlorobiphenyl
39635-33-1	127	3,3',4,5,5'-Pentachlorobiphenyl
38380-07-3	128	2,2',3,3',4,4'-Hexachlorobiphenyl
55215-18-4	129	2,2',3,3',4,5-Hexachlorobiphenyl
52663-66-8	130	2,2',3,3',4,5'-Hexachlorobiphenyl
61798-70-7	131	2,2',3,3',4,6-Hexachlorobiphenyl
38380-05-1	132	2,2',3,3',4,6'-Hexachlorobiphenyl
35694-04-3	133	2,2',3,3',5,5'-Hexachlorobiphenyl
52704-70-8	134	2,2',3,3',5,6-Hexachlorobiphenyl
52744-13-5	135	2,2',3,3',5,6'-Hexachlorobiphenyl
38411-22-2	136	2,2',3,3',6,6'-Hexachlorobiphenyl
35694-06-5	137	2,2',3,4,4',5-Hexachlorobiphenyl
35065-28-2	138	2,2',3,4,4',5'-Hexachlorobiphenyl
56030-56-9	139	2,2',3,4,4',6-Hexachlorobiphenyl
59291-64-4	140	2,2',3,4,4',6'-Hexachlorobiphenyl
52712-04-6	141	2,2',3,4,5,5'-Hexachlorobiphenyl
41411-61-4	142	2,2',3,4,5,6-Hexachlorobiphenyl
68194-15-0	143	2,2',3,4,5,6'-Hexachlorobiphenyl
68194-14-9	144	2,2',3,4,5',6-Hexachlorobiphenyl

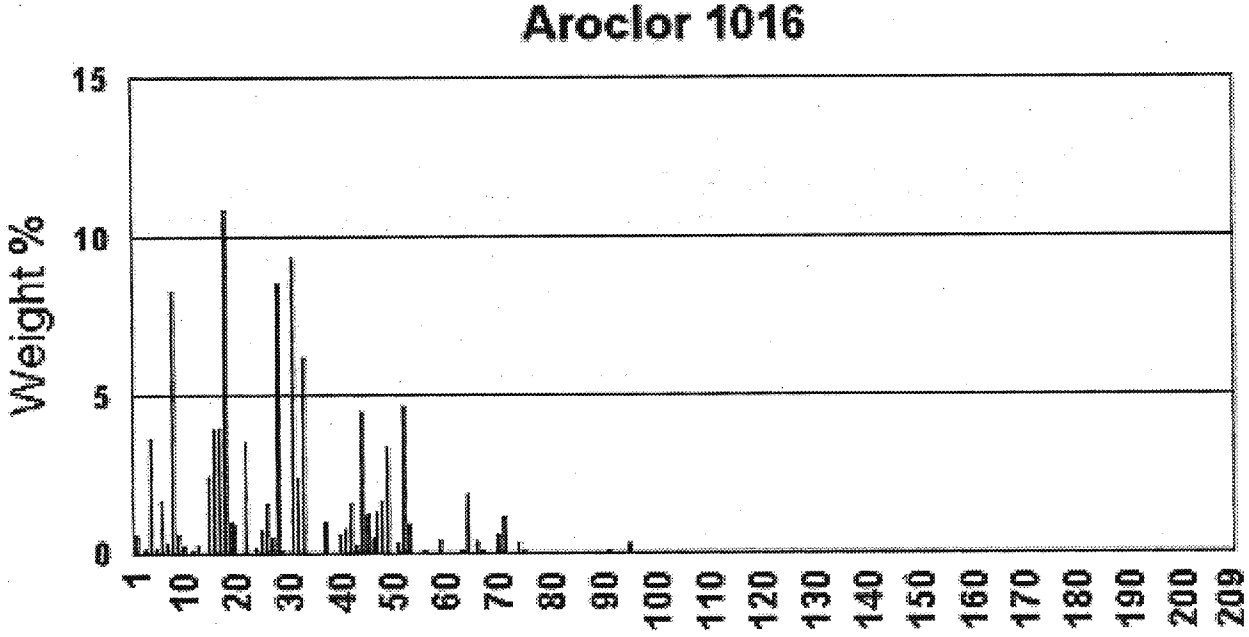
CASRN	Congener Number	IUPAC Name
74472-40-5	145	2,2',3,4,6,6'-Hexachlorobiphenyl
51908-16-8	146	2,2',3,4',5,5'-Hexachlorobiphenyl
68194-13-8	147	2,2',3,4',5,6-Hexachlorobiphenyl
74472-41-6	148	2,2',3,4',5,6'-Hexachlorobiphenyl
38380-04-0	149	2,2',3,4',5',6-Hexachlorobiphenyl
68194-08-1	150	2,2',3,4',6,6'-Hexachlorobiphenyl
52663-63-5	151	2,2',3,5,5',6-Hexachlorobiphenyl
68194-09-2	152	2,2',3,5,6,6'-Hexachlorobiphenyl
35065-27-1	153	2,2',4,4',5,5'-Hexachlorobiphenyl
60145-22-4	154	2,2',4,4',5,6'-Hexachlorobiphenyl
33979-03-2	155	2,2',4,4',6,6'-Hexachlorobiphenyl
38380-08-4	156	2,3,3',4,4',5-Hexachlorobiphenyl
69782-90-7	157	2,3,3',4,4',5'-Hexachlorobiphenyl
74472-42-7	158	2,3,3',4,4',6-Hexachlorobiphenyl
39635-35-3	159	2,3,3',4,5,5'-Hexachlorobiphenyl
41411-62-5	160	2,3,3',4,5,6-Hexachlorobiphenyl
74472-43-8	161	2,3,3',4,5',6-Hexachlorobiphenyl
39635-34-2	162	2,3,3',4',5,5'-Hexachlorobiphenyl
74472-44-9	163	2,3,3',4',5,6-Hexachlorobiphenyl
74472-45-0	164	2,3,3',4',5',6-Hexachlorobiphenyl
74472-46-1	165	2,3,3',5,5',6-Hexachlorobiphenyl
41411-63-6	166	2,3,4,4',5,6-Hexachlorobiphenyl
52663-72-6	167	2,3',4,4',5,5'-Hexachlorobiphenyl
59291-65-5	168	2,3',4,4',5',6-Hexachlorobiphenyl
32774-16-6	169	3,3',4,4',5,5'-Hexachlorobiphenyl
35065-30-6	170	2,2',3,3',4,4',5-Heptachlorobiphenyl
52663-71-5	171	2,2',3,3',4,4',6-Heptachlorobiphenyl
52663-74-8	172	2,2',3,3',4,5,5'-Heptachlorobiphenyl
68194-16-1	173	2,2',3,3',4,5,6-Heptachlorobiphenyl
38411-25-5	174	2,2',3,3',4,5,6'-Heptachlorobiphenyl
40186-70-7	175	2,2',3,3',4,5',6-Heptachlorobiphenyl
52663-65-7	176	2,2',3,3',4,6,6'-Heptachlorobiphenyl
52663-70-4	177	2,2',3,3',4,5',6'-Heptachlorobiphenyl
52663-67-9	178	2,2',3,3',5,5',6-Heptachlorobiphenyl
52663-64-6	179	2,2',3,3',5,6,6'-Heptachlorobiphenyl
35065-29-3	180	2,2',3,4,4',5,5'-Heptachlorobiphenyl
74472-47-2	181	2,2',3,4,4',5,6-Heptachlorobiphenyl
60145-23-5	182	2,2',3,4,4',5,6'-Heptachlorobiphenyl
52663-69-1	183	2,2',3,4,4',5',6-Heptachlorobiphenyl
74472-48-3	184	2,2',3,4,4',6,6'-Heptachlorobiphenyl
52712-05-7	185	2,2',3,4,5,5',6-Heptachlorobiphenyl
74472-49-4	186	2,2',3,4,5,6,6'-Heptachlorobiphenyl
52663-68-0	187	2,2',3,4',5,5',6-Heptachlorobiphenyl
74487-85-7	188	2,2',3,4',5,6,6'-Heptachlorobiphenyl
39635-31-9	189	2,3,3',4,4',5,5'-Heptachlorobiphenyl
41411-64-7	190	2,3,3',4,4',5,6-Heptachlorobiphenyl
74472-50-7	191	2,3,3',4,4',5',6-Heptachlorobiphenyl
74472-51-8	192	2,3,3',4,5,5',6-Heptachlorobiphenyl
69782-91-8	193	2,3,3',4',5,5',6-Heptachlorobiphenyl
35694-08-7	194	2,2',3,3',4,4',5,5'-Octachlorobiphenyl
52663-78-2	195	2,2',3,3',4,4',5,6-Octachlorobiphenyl

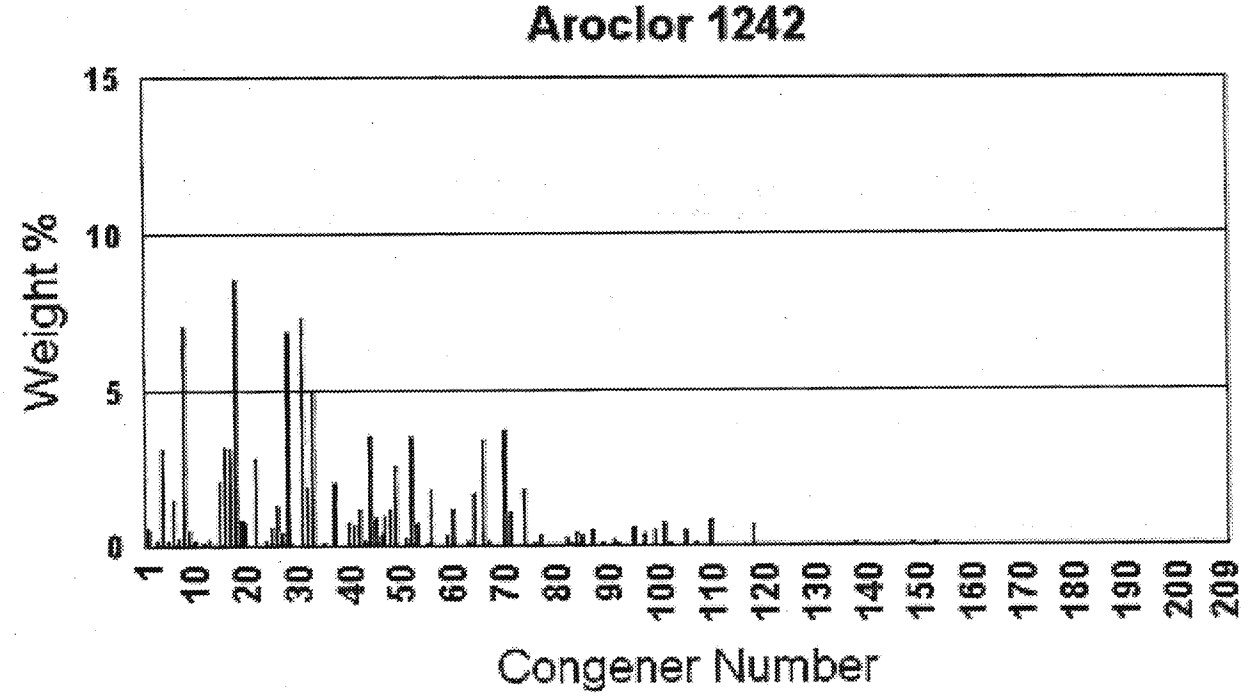
CASRN	Congener Number	IUPAC Name
42740-50-1	196	2,2',3,3',4,4',5,6'-Octachlorobiphenyl
33091-17-7	197	2,2',3,3',4,4',6,6'-Octachlorobiphenyl
68194-17-2	198	2,2',3,3',4,5,5',6-Octachlorobiphenyl
52663-75-9	199	2,2',3,3',4,5,5',6'-Octachlorobiphenyl
52663-73-7	200	2,2',3,3',4,5,6,6'-Octachlorobiphenyl
40186-71-8	201	2,2',3,3',4,5',6,6'-Octachlorobiphenyl
2136-99-4	202	2,2',3,3',5,5',6,6'-Octachlorobiphenyl
52663-76-0	203	2,2',3,4,4',5,5',6-Octachlorobiphenyl
74472-52-9	204	2,2',3,4,4',5,6,6'-Octachlorobiphenyl
74472-53-0	205	2,3,3',4,4',5,5',6-Octachlorobiphenyl
40186-72-9	206	2,2',3,3',4,4',5,5',6-Nonachlorobiphenyl
52663-79-3	207	2,2',3,3',4,4',5,6,6'-Nonachlorobiphenyl
52663-77-1	208	2,2',3,3',4,5,5',6,6'-Nonachlorobiphenyl
2051-24-3	209	Decachlorobiphenyl

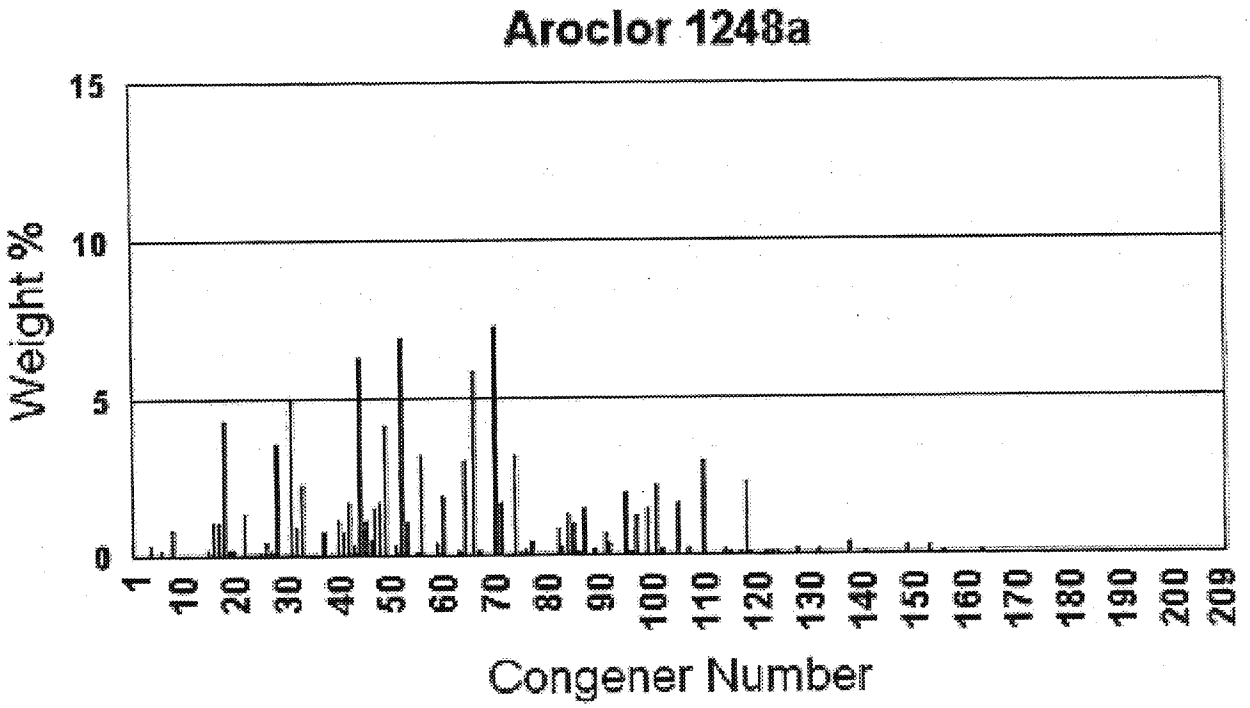
Appendix B PCB Mixtures and Trade Names (EPA 2013d)

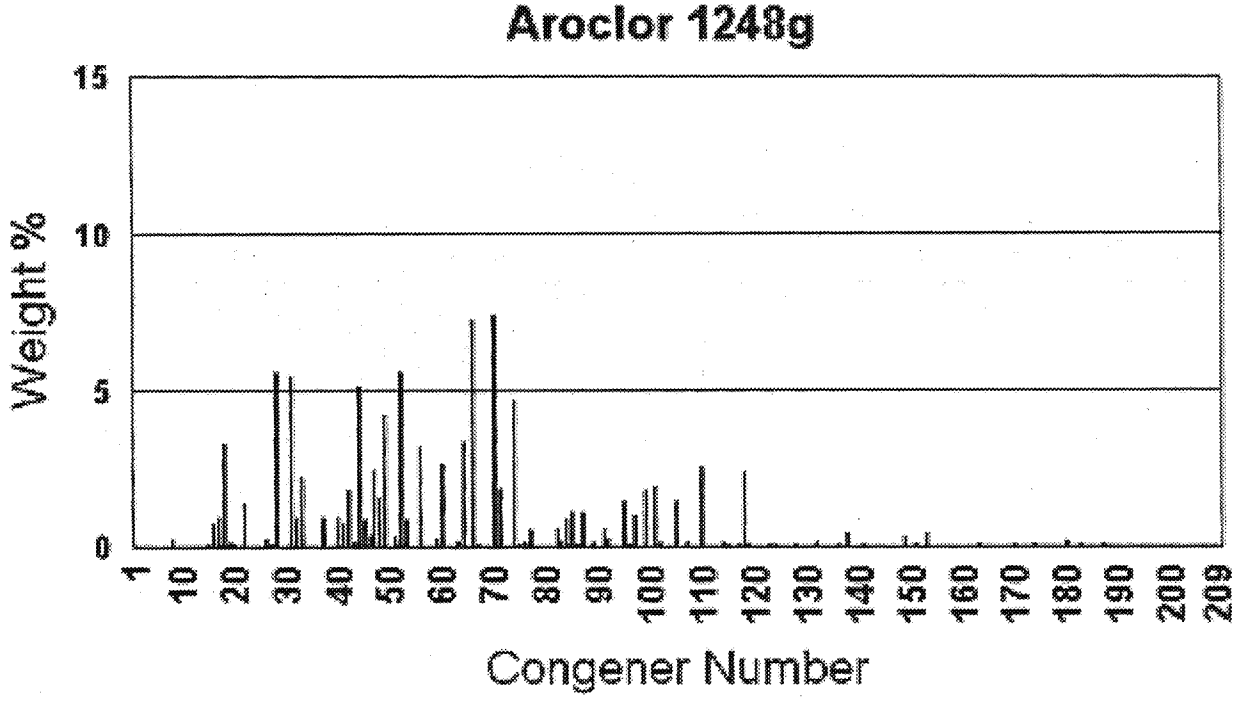
Acector	Dicolor	PCB
Adkarel	Diconal	PCB's
ALC	Diphenyl, chlorinated	PCBs
Apirolio	DK	Pheaoclor
Apirorlio	Duconal	Phenochlor
Arochlor	Dykanol	Phenoclor
Arochlors	Educarel	Plastivar
Aroclor	EEC-18	Polychlorinated biphenyl
Aroclors	Elaol	Polychlorinated biphenyls
Arubren	Electrophenyl	Polychlorinated diphenyl
Asbestol	Elemex	Polychlorinated diphenyls
ASK	Elinol	Polychlorobiphenyl
Askael	Eucarel	Polychlorodiphenyl
Askarel	Fenchlor	Prodelec
Auxol	Fenclor	Pydraul
Bakola	Fenocloro	Pyraclor
Biphenyl, chlorinated	Gilotherm	Pyralene
Chlophen	Hydol	Pyranol
Chloretol	Hyrol	Pyroclor
Chlorextol	Hyvol	Pyronol
Chlorinated biphenyl	Inclor	Saf-T-Kuhl
Chlorinated diphenyl	Inerteen	Saf-T-Kohl
Chlorinol	Inertenn	Santosol
Chlorobiphenyl	Kanechlor	Santotherm
Chlorodiphenyl	Kaneclor	Santothern
Chlorphen	Kennechlor	Santovac
Chorextol	Kenneclor	Solvol
Chorinol	Leromoll	Sorol
Clophen	Magvar	Soval
Clophenharz	MCS 1489	Sovol
Cloresil	Montar	Soltol
Clorinal	Nepolin	Terphenychlore
Clorphen	No-Flamol	Therminal
Decachlorodiphenyl	NoFlamol	Therminol
Delor	Non-Flamol	Turbinol
Delorene	Olex-sf-d	
Diaclor	Orophene	

Appendix C: Distribution of Aroclor mixtures (EPA, 2013d)









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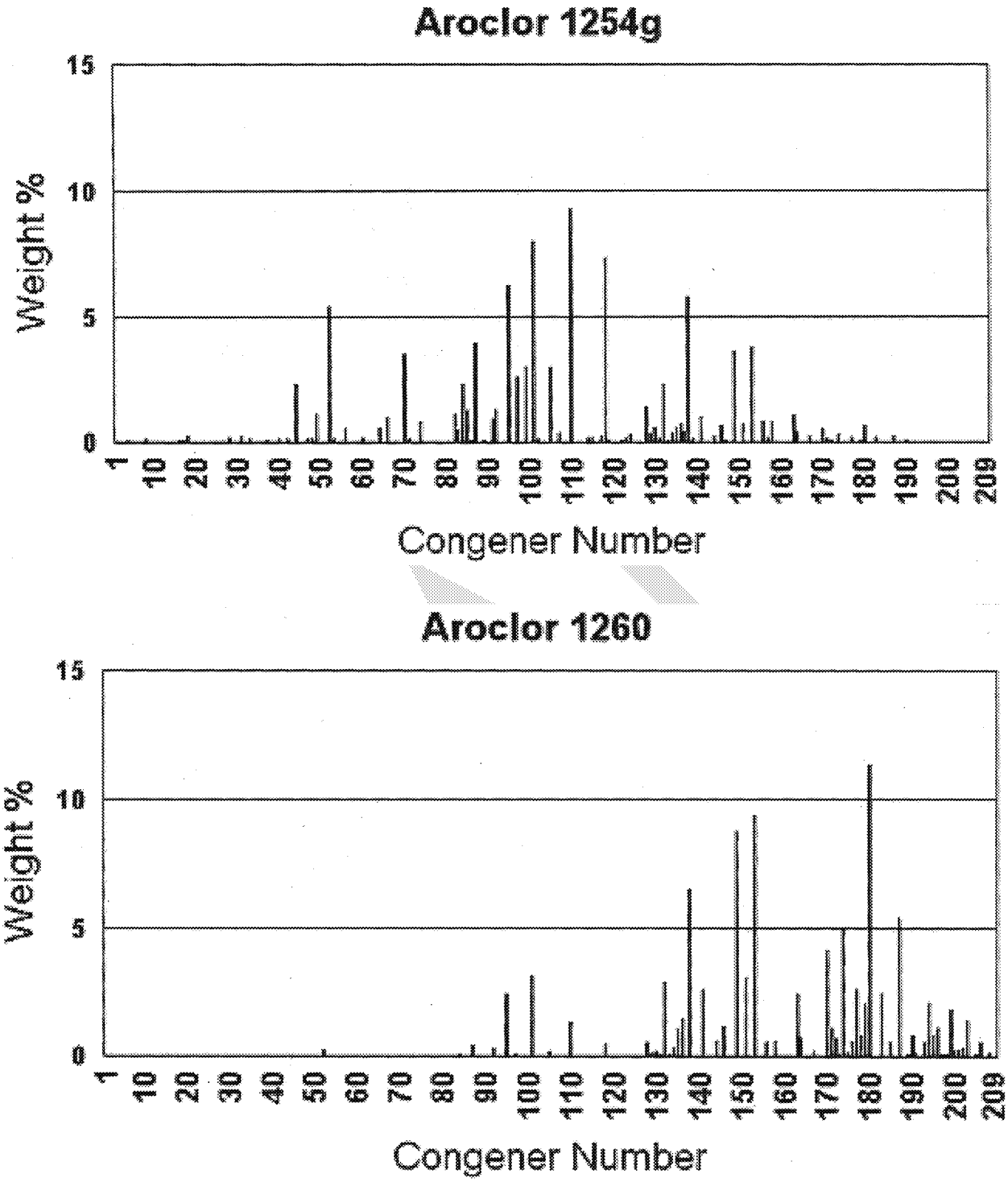
Aroclor 1254g
Weight %
15
10
5
0
1
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
209
Congener Number
Aroclor 1260
Weight %
15
10
5
0
1
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
209
Congener Number

Appendix D: Chemical Processes that have the Potential to Generate PCBs

The following was transcribed from EPA rulemaking records from "Polychlorinated Biphenyls (PCBs); Manufacturing, Processing, Distribution in Commerce, and Use Prohibitions: Exclusions, Exemptions and Use Authorizations" Doc No. OPTS-62032. This was transcribed for Panero et al. (2005).

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPPE U No.
Petroleum Feedstock: BENZENE			
Chlorinated benzenes	Chloronitrobenzenes	Phenol	8
Chlorinated phenols	Dichloronitrobenzenes	Aniline	9
Hexachlorocyclohexane	Dichloroanilines	o-Phenylenediamine	28
Chloranilines	Chlorinated methyl phenols	o-,p-Nitroanilines	29
Trichloroanilines	Chlorophenyl phenylethers	Diphenylamine	34
	Chlorinated benzidines	Acetanilide	17
Petroleum Feedstock: ETHYLENE			
Mono, di-chloroacetic acid	Ethyl chloroacetate	Glycine	108
Sodium chloroacetate	Vinyl chloride	Cyanoacetic acid	111
Chlorinated ethanes	Vinylidene chloride	Sodium, carboxymethyl cellulose	112
Chlorinated ethylenes	Bis (2-chloroethyl) ether	Ethyl cellulose	118
Ethylene chlorohydrin	Chlorinated acetophenones	Ethylene diamine	134
Chlorinated, fluorinated ethanes	Choline chloride	Aminoethylethanolamine	135
Chlorinated, brominated ethylenes	Hexachlorobutadiene	Mono-, di-, and triethylene glycol ethers	150
Chlorinated, fluorinated ethylenes		Tetramethylethylene diamine	(3341)
Chlorinated acetaldehyde			
Chlorinated acetyl chloride			
Hexachlorobenzene			
Petroleum Feedstock: METHANE			
Chlorinated methanes	Chlorinated, fluorinated methanes	Carbon tetrabromide	162
Phosgene	Chlorinated, brominated methanes	Carbon tetrafluoride	(812)
Tetrachloroethane	Bis (chloromethyl) ether		
Chlorodifluoroethane (?)	Cyanuric chloride		
Perchloromethyl mercaptan (?)	Trichloroethylene		
Cyanogen chloride			

Chlorinated Compounds Produced Using Direct Chlorination	Chlorinated Compounds Produced Using Chlorinated Feedstocks	Non-chlorinated Compounds Produced Using Chlorinated Feedstocks	IPPPEU No.
Petroleum Feedstock: NAPHTHALENE			
Chloronaphthalenes			
Tetrachlorophthalic anhydride			
Petroleum Feedstock: PARAFFINS			
n-Propyl chloride		n-Propylamine	231
Carbon tetrachloride		Butyronitrile	232
Perchloroethylene		Amyl amines	243
Hexachloroethane		Amyl alcohols	244
Amyl chlorides		Amyl Mercaptans	245
Chloroprene		Benzophenone	249
Hexachlorocyclopentadiene		Linear alkylbenzenes	(2417)
Methallyl Chloride			
Petroleum Feedstock: PROPYLENE			
Dichlorohydrin	Epichlorohydrin	Isopropylphenols	272
Chloranil	Bis (2-chloroisopropyl) ether	Propylene oxide	280
Propylene chlorohydrin		Anisols	302
Chlorinated propanes		Allyl alcohol	317
Chlorinated propylenes		Glycerol	318/319
		Propyl amines	(1446)
Petroleum Feedstock: TOLUENE			
Benzyl chloride	Benzoyl chloride	Benzyl alcohol	334
Benzyl dichloride		Benzyl amine	335
Benzyl trichloride		Benzamide	337
Chlorotoluenes		Toluenesulfonamide	358
Chlorobenzaldehyde		Benzoyl peroxide	(495)
Chlorobenzoic acids & esters			
Chlorobenzoyl chlorides			
Toluenesulfonyl chloride			
Chlorobenzotrichlorides			

*The IPPEU No. refers to the process description in the 1977 EPA summary (EPA, 1977). Those numbers bracketed by parentheses refer to the OCPDB numbers in the 1980 EPA summary (EPA, 1980)

Appendix E Products Containing PCBs

Known Maximum Concentrations of Non-Liquid Open-System Products Containing PCBs from the Control of Toxic Chemicals in Puget Sound Phase 3: Primary Sources of Selected Toxic Chemicals and Quantities Released in the Puget Sound Basin (Ecology 2012).

Material	PCB content (mg/kg)
Adhesive tape	1,400
Anti-fouling compounds	No data available
Caulking[1]	310,000
Ceiling tiles [2]	53
Cloth/paper insulating material	12,000
Coal-tar enamel coatings	1,264
Dried paint [3]	63,300
Dried paint [4]	97,000
Fiberglass insulation	39,158
Fire retardant coatings	No data available
Flooring and floor wax/sealant [5]	No data available
Fluorescent light ballast potting	No data available
Foam rubber insulation	13,100
Foam rubber parts	1,092
Grout	9,100
Insulating materials in electric cable	280,000
Plastics/plasticizers	13,000
Processed cork ventilation system gasket material	6,400
Roofing/siding material	22,000
Rubber parts	84,000
Sound-dampening material	No data available
Thermal insulation	73,000
Waterproofing compounds	No data available
Wool felt gaskets	688,498

Source: EPA, 1999 (Unless otherwise noted).
1 Kohler et al., 2005 (citing Sundahl et al., 1999) reported concentrations up to 583,000 mg/kg.
2 Weis et al. (2003) reports ceiling panels with 110,000 mg/kg PCB flame retardant coating.
3 Non-degraded gray chlorinated rubber-based paint, Federal specification TT-P-912; PCBs added presumably to prevent brittleness.
4 Semi-gloss paint; white and light blue, Amercoat 33HB with red Amercoat 86 primer.
5 Rudel et al., 2008 found elevated concentrations in indoor air and residents' blood in residence containing PCB

Appendix F Washington transformers in EPA database.

Company	City	Contact	Trans. location ID	Trans. Box no.	Transformer street address	Trans. City	Trans. Zip code	No. of Trans.	Weight (kg)
Puget Sound Energy	Bellevue	John Rork	2241	56	Talcott Avenue & Columbia Street	Olympia	98501	3	7
Puget Sound Energy	Bellevue	John Rork	2209	36	14401 278th Avenue NE	Duval	98019	2	5
Puget Sound Energy	Bellevue	Lea Boyle	2216	1	14401 188th Avenue NE	Redmond	98052	2	4.52
Puget Sound Energy	Bellevue	John Rork	2218	1	S 173rd & 43rd Avenue S	Renton	98055	0	0
Puget Sound Energy	Bellevue	John Rork	2223	2	2211 Nevada Street	Bellingham	98225	0	0
Puget Sound Energy	Bellevue	John Rork	2212	3	24810 156th Avenue SE	Kent	98025	0	0
Puget Sound Energy	Bellevue	John Rork	2248	4	Hodgedon & Garfield Streets	Tenino	98589	0	0
Puget Sound Energy	Bellevue	John Rork	2237	5	70th Street E & Myers Road	Bonney Lk	98390	0	0
Puget Sound Energy	Bellevue	John Rork	2255	6	Dolarway Road	Ellensburg	98922	0	0
Puget Sound Energy	Bellevue	John Rork	2256	7	Jackson & Main Streets	Cle Elum	98922	0	0
Puget Sound Energy	Bellevue	John Rork	2231	8	19319 Electron Road	Orting	98360	0	0
Puget Sound Energy	Bellevue	John Rork	2236	9	W. side of Stottlemeyer Road	Poulsbo	98370	0	0
Puget Sound Energy	Bellevue	John Rork	2211	10	40801 268th Avenue SE	Enumclaw	98022	0	0
Puget Sound Energy	Bellevue	John Rork	2207	11	N. Tapps Highway & Vandermark Road	Auburn	98002	0	0
Puget Sound Energy	Bellevue	John Rork	2213	12	SE 80th Street & 246 Avenue SE	Issaquah	98027	0	0
Puget Sound Energy	Bellevue	John Rork	2208	13	13635 SE 26th	Bellevue	98004	0	0
Puget Sound Energy	Bellevue	John Rork	2227	14	3975 E. Highway 525	Langley	98260	0	0
Puget Sound Energy	Bellevue	John Rork	2222	15	1274 Thompson Road	Anacortes	98221	0	0
Puget Sound Energy	Bellevue	John Rork	2220	16	2857 S. 221st	Des Moines	98148	0	0
Puget Sound Energy	Bellevue	John Rork	2225	17	12251 Mt Baker Highway	Glacier	98244	0	0
Puget Sound Energy	Bellevue	John Rork	2226	18	7537 Portal Way	Ferndale	98248	0	0

Company	CIty	Contact	Trans. location ID	Trans. Box no.	Transformer street address	Trans. City	Trans. Zip code	No. of Trans.	Weight (kg)
Puget Sound Energy	Bellevue	John Rork	2215	19	13635 NE 80th	Redmond	98052	0	0
Puget Sound Energy	Bellevue	John Rork	2243	20	9512 Pacific Highway SE	Lacey	98503	0	0
Puget Sound Energy	Bellevue	John Rork	2242	21	9221 Wilows Road NE	Redmond	98502	0	0
Puget Sound Energy	Bellevue	John Rork	2217	22	34717 21st Avenue SW	Federal Way	98003	0	0
Puget Sound Energy	Bellevue	John Rork	2210	23	1035 Stevenson Avenue	Enumclaw	98022	0	0
Puget Sound Energy	Bellevue	John Rork	2245	24	Hanford Road & Centralia Steam Plt	Centralia	98531	0	0
Puget Sound Energy	Bellevue	John Rork	2219	25	South of I-90 between Exits 37 & 38	Snoqualmie	98065	0	0
Puget Sound Energy	Bellevue	John Rork	2229	26	Corner of Central Valley Road & Bucklin	Bremerton	98310	0	0
Puget Sound Energy	Bellevue	John Rork	2230	27	20th Street E & 169th Avenue E (2111)	Sumner	98340	0	0
Western Washington University	Bellingham	Gayle Shipley	2224	1	Commissary 781 25th St.	Bellingham	98225	0	0
SDS Lumber Co	Bingen	Ronald Schultz	2249		South Side BNSF RR	Bingen	98605	2	2138
Kimberly-Clark Worldwide	Everett	Jim Ketchum	2221	1	2600 Federal Ave.	Everett	98201	0	0
Grays Harbor Paper L.P.	Hoquiam	Richard Johnston	2246	1	801 23rd St.	Hoquiam	98550	5	50932
Reynolds Metals Company	Longview	H.S. Hays	2250	1	4029 Industrial Way	Longview	98632	0	0
Washington Veneer	Omak	Joe Atwood	2254		1100 Eighth Ave.E.	Omak	98841	7	12412
PUD. No. 1 of Clallam Co	Port Angeles	Quimby Moon	2232		1936 West 18th Street	Port Angeles	98362	4	505
City of Port Angeles	Port Angeles	Mark Shamp	3507	1	321 E. Fifth Street	Port Angeles	98362	1	
PUD. No. 1 of Clallam Co	Port Angeles	Quimby Moon	2234	1	1936 West 18th Street	Port Angeles	98363	1	100
PUD No. 1 of Clallam Co	Port Angeles	Quimby Moon	6857		1936 West 18th Street	Port Angeles	98363	1	68
Port Townsend Paper Corporation	Port Townsend	John M. Recht	2235	1	100 Mill Hill Rd	Port Townsend	98368	0	0
City of Richland	Richland	Wayne Collop	2261		806 Thayer Drive	Richland	99352	2	45
US Dept of Energy Richland Oper. Office	Richland	B.J. Dixon	2260	1	200 East Area	Richland	99352	1	137

Company	CIty	Contact	Trans. location ID	Trans. Box no.	Transformer street address	Trans. City	Trans. Zip code	No. of Trans.	Weight (kg)
Energy Northwest	Richland	J.P. Chasse	2900	1	HPCS Diesel Generator Rm, Nuclear Plant #2, N. Power Plant Loop	Blank	Blank	0	0
Entercom Communications Corp	Seattle	Martin Hadfield	2475	1	910 Lone Oak Road	Longview	Blank	0	0
Total Reclaim, Inc	Seattle	Craig Lorch	3445	1	2200 Sixth Avenue South	Seattle	98134	1	215
Seattle City Light	Seatle	Karen Dinehart	2958	23	Laurelhurst Lane and 51st	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2421	2	4502 NE 41st Street	Seattle	98124	3	182
Seattle City Light	Seattle	Karen Dinehart	2519	1	Bellevue Ave E & E. John	Seattle	98124	3	160
Seattle City Light	Seattle	Karen Dinehart	2383	3	2826 NW Market Street	Seattle	98124	2	114
Seattle City Light	Seattle	Karen Dinehart	2459	4	7710 35th Avenue, SW	Seattle	98124	1	68
Seattle City Light	Seattle	Karen Dinehart	2448	5	6730 24th Avenue, NW	Seattle	98124	0	0
Seattle City Light	Seattle	Karen. Dinehart	2331	6	1414 NW Leary Way	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2460	7	7750 28th Ave NW	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2329	8	1405 NW 65th Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2465	9	8032 15th Avenue NW	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2395	10	3209 NW 65th Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2373	11	2333 W Boston Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2368	12	2100 SW Andover Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2406	13	35th Ave SE & SW Genessee	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2436	14	5601 23rd Avenue SW	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2342	15	1605 SW Holden Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2403	16	3405 SW Graham Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2416	17	4118 SW Morgan Street	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2477	18	9370 52nd Avenue S	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2354	19	1stE/Of Earl Ave NW, S/SI NW 90th	Seattle	98124	0	0

Company	CIty	Contact	Trans. location ID	Trans. Box no.	Transformer street address	Trans. City	Trans. Zip code	No. of Trans.	Weight (kg)
Seattle City Light	Seattle	Karen Dinehart	2355	20	1stN/Of S Holden,E/SI Rainier AveS	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2356	21	1stS/Of W Bertona,E/SI 21st Ave W	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2425	24	48th NE & 47th NE	Seattle	98124	0	0
Seattle City Light	Seattle	Karen Dinehart	2431	22	51st Ave NE & NE 41st Street	Seattle	98124	0	0
Inland Power and Light	Spokane	Todd Hoffman	2257		10110 W. Hallett Road	Spokane	99014		1,249.00
Avista Utilities	Spokane	Clarice Robertson	3376		various locations	Blank	Blank	157	16,434.00
Avista Corporation	Spokane	Clarice Robertson	3049	1	Onion Creek Road	Colville	Blank	0	0
Avista Corporation	Spokane	Clarice Robertson	3274	2	SE corner of Rockwell and Monroe Streets	Spokane	Blank	0	0
Tacoma Power	Tacoma	Russell Post	2247	1	418 Gershick Rd	Silver Creek	98585	10	830
Tacoma School District #10	Tacoma	Margaret Ohlson	2238	2	111 North E Street	Tacoma	98403	1	358
Tacoma School District #10	Tacoma	Margaret Ohlson	2239	1	2502 North Orchard	Tacoma	98406	1	358
Pioneer Americas, Inc./Chlor Alkali Co. Inc.	Tacoma	Karl Iams	2240	1	605 Alexander Ave.	Tacoma	98421	0	0

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